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Lake Calumet Cluster Site Group

Field Sampling Plan

Operable Unit Two

Lake Calumet Cluster Site
Chicago, Illinois

July 2015 w/ ERRATA SHEET DATED 9-30-2015

ERRATA
Field Sampling Plan
Remedial Investigation and Feasibility Study
Lake Calumet Cluster Site, Operable Unit 2, Chicago, Illinois
September 30, 2015

The following changes are hereby made to the *Field Sampling Plan for Operable Unit Two* (dated July 17, 2015) for the Lake Calumet Cluster Site in Chicago, Illinois (LCCS).

Page 6: Replace paragraph 2 with the following:

Groundwater samples will be collected through the drilling rods, which will be attached to a Geoprobe® screen-point sampling device. The sampling procedure is summarized below:

- The screen-point sampler will be driven to the bottom of the target interval. After reaching the target depth, the drill string will be pulled up approximately two feet, exposing the screen to the target sample interval.

- A peristaltic pump or bladder pump will then be positioned with the pump intake in the center of the screened interval.

- The pump will be used to purge groundwater from the sample interval until the following conditions are met:

  - A minimum of three tooling volumes of groundwater (i.e., three times the inner volume of the water within the drill string) has been removed;

  - No fluorescent dye (as introduced during HPT drilling) is visible in the purged water; and

  - In the judgment of field personnel, as indicated by visual observations of turbidity, representative groundwater is being obtained.

- After purging is complete, the flow rate will be reduced to allow sample collection directly into laboratory-supplied containers.

- The samples will be analyzed for Target Compound List (TCL) volatile organic compounds (VOCs), ammonia, and dissolved and total metals.

Page 8: Insert the following after the first sentence of item #3:

> The intake of the pump will be placed at the mid-point of the submerged portion of the well screen.

Page 19: In section 6.2, with respect to down-well equipment, revise Item 3 to read:

> 3. Rinse with de-ionized or distilled water.

Page 20: In section 6.2, with respect to submersible pumps, revised Item 5 to read:

> 5. Flush de-ionized or distilled water solution through the pump by immersing the pump in the solution, without tubing attached, and turning the pump on.

ARCADIS

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Field Sampling Plan

Operable Unit Two

Lake Calumet Cluster Site

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1. Introduction

The purpose of this Field Sampling Plan (FSP) is to present the field procedures that will be used to conduct the Remedial Investigation (RI) for Operable Unit Two (OU2) at the Lake Calumet Cluster Site (LCCS or Site), as described in the approved Remedial Investigation/Feasibility Study Work Plan (RI/FS Work Plan). The United States Environmental Protection Agency (USEPA) approved the RI/FS Work Plan on July XX, 2015.

The following activities are covered by this FSP:

- Installation of piezometers;
- Measurement of water levels in newly installed piezometers;
- Hydraulic Profiling Tool (HPT) testing;
- Vertical aquifer profile (VAP) sample collection;
- Monitoring well installation; and
- Groundwater sampling.

This FSP is derived from field sampling protocols that are based on technically sound, standard practices such as those published in the "Handbook for Sampling and Preservation of Water and Wastewater," USEPA and Standard Operating Procedures (SOPs) developed by ARCADIS U.S., Inc. (ARCADIS).

1.1 Project Team Roles and Responsibilities

This project will be managed in accordance with the following section. The ARCADIS project organizational structure will be clearly communicated through this plan and during planning meetings to ensure that all team members are familiar with their expected roles in completing a specific assignment. A project organization chart for the Remedial Investigation/Feasibility Study (RI/FS) is shown on Figure 1.

The management responsibilities are described below:

USEPA Project Coordinator: Shari Kolak of the Superfund Division Region 5 is the designated USEPA Project Coordinator.

Technical Project Coordinator: Leo M. Brausch will serve as the Technical Project Coordinator for the LCCS Group. Mr. Brausch will be the primary point-of-contact for the USEPA Project Coordinator and will coordinate the activities of ARCADIS.

ARCADIS RI/FS Project Manager: Jack Kratzmeyer

- Management of ARCADIS project team;
- Primary point-of-contact for the LCCS Group's Technical Project Coordinator;
- Meetings with USEPA, Illinois EPA (IEPA), and the LCCS Group;
- Direction of Technical Task Managers;
- Data evaluation;
- Preparation and review of RI/FS Work Plan and supporting plans (FSP, Quality Assurance Project Plan [QAPP], and Health and Safety Plan [HASP]); and
- Technical representative for project activities.

ARCADIS Technical Task Managers

The ARCADIS Technical Task Managers are responsible for the task-specific aspects of the Work Plan and related plans. The Task Managers report to the Project Manager.

The Task Managers are listed below:

Remedial Investigation Task Manager	Tom Darby
Feasibility Study Task Manager	Andy Pennington
Risk Assessment Task Manager	Amber Stojak

1.2 Site and Project Description

A description of the Site and a summary of the pertinent site background and operating history are presented in Section 2 of the RI/FS Work Plan. This FSP specifically addresses the field procedures that will be followed during implementation of the RI/FS Work Plan. A site layout is included as Figure 2.

2. Sampling Program, Procedures, and Equipment

Sampling and site characterization activities conducted as part of the remedial investigation will include installing piezometers, measuring water levels in the newly installed piezometers, performing HPT analyses, collecting VAP samples, installing monitoring wells, and groundwater sampling.

Procedures to be used during each of these RI activities are discussed in the following sections.

2.1 Piezometer Installation

Piezometers will be installed using direct push technology. At each location, a soil core will be collected from the ground surface to a depth of approximately 20 feet below ground surface. The soil cores will be logged to characterize the lithology and determine the depth of the water table. The final depth of each boring will be determined in the field and will be adjusted based on the depth at which water is encountered.

The piezometers will be one-inch diameter, Schedule 40 polyvinyl chloride (PVC), 10-slot well screen completed with a pre-packed sand filter. The riser will be a Schedule 40 PVC riser which will extend two to three feet above ground surface. Filter sand will then be added on top of the pre-pack to increase the sand level to a minimum of one foot above the top of the well screen. Bentonite will be used to finish the well.

Piezometers will then be developed to ensure communication with the surrounding formation. This will be completed in accordance with the ARCADIS SOP for developing groundwater wells in Attachment 1. Development will be complete when the water is free of visible sediment and the pH, temperature, turbidity, and conductivity are stable within 10 percent for three consecutive readings. If development methods are unable to achieve these metrics, development will be considered complete after five well volumes of water have been removed.

2.2 Water Level Measurement

Monthly water-level gauging events will be conducted at the Site following installation of the piezometer. Groundwater levels will be measured at each piezometer during every gauging event. The groundwater levels will be measured to the nearest 0.01 foot from the north side of the top of the casing, using a Solinst Model 101 electric water level indicator, or equivalent. The total depth of the piezometer from the reference point (*i.e.,* top of casing) will also be measured to ±0.01 foot using a pre-cleaned, weighted measuring tape or by using the electric water level indicator (accounting for any vertical separation between the bottom of the weighted portion of the water level indicator tape and the electrical conductivity sensor used to identify immersion in water).

2.3 Hydraulic Profiling Tool

Hydraulic Profiling Tool (HPT) soundings will be completed during the remedial investigation to provide a real-time, continuous profile of relative soil permeability with depth within the unconsolidated deposits that are present at the Site. The resulting profile can be used to identify hydrostratigraphic units, and will guide subsequent VAP groundwater sampling (used to determine from which depth intervals to collect groundwater samples).

The HPT borings will be completed along transects oriented perpendicular, and potentially parallel to the groundwater flow direction. The data collected will be used to develop high resolution cross-sections of the hydrostratigraphic units that control groundwater flow. The preliminary layout of the HPT borings is shown on Figure 2. The HPT soundings will be completed using the SOPs for the use of the geoprobe HPT provided in Attachment 1.

Prior to beginning the HPT borings, pre-test calibrations will be performed to ensure the HPT pressure and electrical conductivity responses are consistent with expected values. ARCADIS field staff will oversee this calibration process and document it in field notes. The HPT will then be advanced into the subsurface. At each location, the HPT sounding will be completed first to provide a vertical profile of the relative permeability throughout the depth investigated. The HPT will be attached to the end of a Geoprobe® drill string to support a continuously metered injection of a small volume of water and fluorescent dye mixture during advancement of the probe. Simultaneously, the injected fluid backpressure will be measured and logged at frequent intervals along with the flow data. After correcting for the equipment head losses, the flow and pressure will be plotted as a relative permeability (or hydraulic conductivity) curve by recognizing that hydraulic conductivity (K) is the constant of proportionality of flow divided by pressure. The resulting data (flow and pressure) from each location will be compared across the entire vertical profile at each boring location and between soundings along all transects.

The HPT probe is generally able to resolve the relative permeability of soils and other unconsolidated materials with a hydraulic conductivity of 10^{-2} centimeter per second (cm/sec) or lower. If the HPT profiles indicate the soil hydraulic conductivity is generally lower than 10^{-2} cm/sec, hydraulic testing (*i.e.*, slug tests at discrete intervals) will be completed at several depth intervals to verify and calibrate the HPT results. Conversely, if the HPT indicates that a majority of the aquifer at the Site has a hydraulic conductivity greater than 10^{-2} cm/sec, and too high to be resolved effectively by HPT probe, HPT will be discontinued and hydraulic testing will be completed at additional sample intervals to help estimate the mass flux across the transect.

During the course of the HPT work, a soil boring will also be advanced adjacent to select HPT borings. Soil cores will be collected using either a dual tube or piston style sampler to the total depth of the HPT boring. Soil cores will be collected at approximately 30 percent of the HPT locations. The cores will allow comparison of the HPT results to conventional soil descriptions based on visual observations and correlate HPT results to observed soil types, supporting a more detailed understanding of site hydrostratigraphy. A detailed boring log will be prepared by the onsite geologist and compared to the HPT response. The comparison of the soil borings to the HPT results will provide a better understanding of how the specific lithologic units within the deposits respond to the HPT.

Hydraulic conductivity testing will be completed at selected intervals along the borehole using a Geoprobe® model GW1600 pneumatic slug test kit or equivalent. The intervals for testing will be chosen based on HPT response, and selected to characterize hydraulic conductivities across the range of observed HPT responses. The pneumatic slug test device will be placed at the top of the well and air will be introduced into the boring quickly, causing a measurable change in water level. The field staff will measure the water level response to the initial change at closely spaced intervals in order to define the water level response curve. The field staff will continue monitoring and recording the depth-time measurements until the water level has equilibrated.

2.4 Vertical Aquifer Profiling

The VAP will be initiated after all of the HPT soundings have been completed. The VAP groundwater samples will be collected from a separate boring at each HPT location that will be advanced using direct-push drilling methods. The boring will be as close as possible to the HPT location. Groundwater samples will be collected from the VAP borings at discrete intervals along the vertical profile. Prior to starting the borings for collection of the VAP samples, the HPT data will be evaluated and the permeable zones identified at each VAP sampling location. The permeable zones will be the target for collection of the VAP samples because these areas represent the potential groundwater transport pathways at the Site. The groundwater samples will be collected at each location beginning at the water table and continuing at 5- to 10-foot intervals until the base of the borehole is reached. An estimated five samples will be collected at each location; however, additional samples may be added as necessary to adequately characterize the permeable flow zones.

Groundwater samples will be collected through the drilling rods, which will be attached to a Geoprobe® screen-point sampling device. The screen-point sampler will be driven to the bottom of the target interval. After reaching the target depth, the drill string will be pulled up approximately two feet, exposing the screen to the target sample interval. A peristaltic pump or bladder pump will then be used to purge groundwater from the sample interval until, in the judgment of field personnel, representative groundwater is being obtained (as indicated by visual observations of turbidity). After purging is complete, the flow rate will be reduced to allow sample collection in to 40 ml volatile organic analysis (VOA) vials. At each proposed sample interval, a minimum of three tooling volumes of groundwater (*i.e.*, three times the inner volume of the water within the drill string) will be removed prior to sample collection. No sample will be taken until the fluorescent dye introduced during HPT drilling is no longer visible in the water. This ensures that the water introduced during the HPT phase of work is not sampled. The samples will be analyzed for Target Compound List (TCL) volatile organic compounds (VOCs), ammonia, and dissolved and total metals.

Re-write

Groundwater samples will be packed on ice and shipped to the project laboratory under appropriate chain-of-custody procedures. The majority of samples will be analyzed using a standard laboratory turnaround time; however, it will be necessary to analyze some of the initial samples on an expedited turnaround (24 to 48 hours) to aid in determining that the depths of the boreholes are sufficient to achieve vertical delineation of the constituents.

2.5 Monitoring Well Installation

The data collected during the HPT and VAP portion of the remedial investigation will be used to determine locations for the installation of new monitoring wells. The number of wells will be determined based on the results of the HPT/VAP sampling. The new monitoring wells will be installed using hollow-stem auger (HSA) drilling methods. Monitoring wells will be installed by a qualified drilling subcontractor under the supervision of an ARCADIS geologist. Monitoring well installation activities will be conducted in accordance with the corresponding SOP provided in Attachment 1. Following installation, the newly installed groundwater monitoring wells will be developed to ensure adequate hydraulic communication with the surrounding formation. Development will be completed using a combination of surging and pumping/over-pumping development methods. Development will be complete when the water is free of visible sediment, and the pH, temperature, turbidity, and conductivity are stable within 10 percent for three consecutive readings.

Decontamination and waste management procedures to be used during well installation are discussed in the following sections.

2.6 Groundwater Sampling

The new monitoring wells installed will be sampled for the following list of analytes:

- TCL VOCs, SVOCs, PCBs, and pesticides;
- Total and dissolved Target Analyte List (TAL) metals;
- Nitrogen compounds: ammonia-N, nitrate-N, and nitrite-N;
- Geochemical characterization parameters: sulfate, sulfide, total suspended solids (TSS), and total organic carbon (TOC); and
- Dissolved gases: methane, carbon dioxide, oxygen, and nitrogen.

The sample container, preservation methods and holding time requirements for the laboratory analyses to be performed are identified in the QAPP. The groundwater samples will be submitted to TestAmerica in University Park, Illinois (project laboratory) for chemical analysis.

Groundwater samples will be collected for analysis using either a submersible or peristaltic pump. Down-well sampling equipment (other than single-use, disposable tubing) will be decontaminated between sampling locations as discussed in Section 6. Purge water and other investigation derived waste will be managed as discussed in Section 7. SOPs for groundwater sampling are provided in Attachment 1.

The following protocol will be followed for sampling:

1. The groundwater level will be measured to the nearest 0.01 foot using a pre-cleaned Solinst Model 101 electric water level indicator, or equivalent. Field calibration and preventative maintenance requirements are discussed in Section 5.

2. The total depth of the monitoring well from the reference point (*i.e.*, top of casing) will be measured to ±0.01 foot using a pre-cleaned, weighted measuring tape or by using the electric water level indicator (accounting for any vertical separation between the bottom of the weighted portion of the water level indicator tape and the electrical conductivity sensor used to identify immersion in water). The measured well depth will be compared to the constructed well depth to identify the presence of any sediment that may have accumulated at the bottom of the well. The depth of any well bottom sediment will be considered when positioning the pump intake to avoid mobilizing the sediment while purging.

3. Purging will be conducted using a pre-cleaned stainless steel submersible pump or peristaltic pump. The pumping rate will be designed to minimize drawdown and will not exceed 500 milliliters per minute (mL/min). The groundwater level will be measured while purging to ensure that less than 0.3 feet of drawdown occurs. While purging, the pumping rate and groundwater level will be measured and recorded every 5 minutes.

4. Stabilization of the purged groundwater is necessary prior to sampling to ensure that the samples obtained are representative of groundwater in the subsurface only and not influenced by stagnant groundwater stored in the well casing. The field parameters pH, temperature, conductivity, oxidation-reduction (redox) reaction potential (ORP), dissolved oxygen (DO), and turbidity will be monitored while purging to evaluate the stabilization of the purged groundwater. The field parameters will be measured and recorded every 5 minutes (or as appropriate) using a Groundwater Sampling Log. Stabilization will be considered to be achieved when three consecutive recorded readings for each parameter are within the following limits:

pH	±0.1 pH units of the average value of the three readings;
temperature	±3 percent of the average value of the three readings;
conductivity	±3 percent of the average value of the three readings;

ORP	±10 millivolts (mV) of the average value of the three readings;
DO	±10 percent of the average value of the three readings; and
turbidity	±10 percent of the average value of the three readings, or a final value of less than 10 nephelometric turbidity units (NTU).

pH, conductivity, temperature, ORP, DO, and turbidity will be monitored using an In-Situ Model TROLL 9500 XP instrument or equivalent. Field calibration, preventative maintenance, and SOPs are contained in Section 5.0. At the start of purging, the purge water will be visually inspected for water clarity prior to connecting the flow-through-cell. If the purge water appears extremely turbid, purging will be continued until the purge water becomes visibly less turbid before connecting the flow-through-cell.

In general, stabilization of the individual field parameters is expected to occur in the order listed above. Should stabilization not be achieved for all field parameters, purging will be continued for a minimum of 60 minutes. After 60 minutes, collected readings and water level measurements will be evaluated in the field. If, in the judgment of field personnel, representative groundwater is being obtained from the formation, but parameter stabilization is not likely to occur in a reasonable timeframe, sampling will proceed and the field decision will be noted. If samples are not judged to be representative, purging will continue or sampling of the well will be postponed and re-development of the well will be evaluated.

In the event that the groundwater recharge to the monitoring well is insufficient to conduct the minimal drawdown protocol, the well will be pumped dry and allowed to sufficiently recharge prior to sampling. Wells which are purged dry will not be subject to the above purging criteria.

Groundwater samples will be collected from the wells as described below:

1. The flow-through-cell will be disconnected prior to obtaining the sample. The discharge line from the pump will be positioned at the base of the sample bottle. All required preservatives will be added to the samples in advance by the

appropriate laboratory. The sample bottle will be filled from the bottom to the top.

2. Each VOC sample vial will be inspected for the presence of bubbles. If bubbles are observed, the sampler will attempt to add sample volume to the vial to remove the bubbles. If bubbles continue to form, indicating effervescence, the sample will be discarded and recollected. The laboratory will be notified that the samples are unpreserved and the analyses will be completed within the appropriate hold time.

3. All equipment used during sampling will be decontaminated. Single-use tubing will be disposed of after the well has been sampled.

4. Quality control (QC) samples will be collected for chemical analysis as discussed in Section 3.

5. Sample containers will be placed in the sample cooler with packing material and bagged ice and will be held at or below 4 degrees Celsius prior to and during shipment to the project laboratory. The samples will be shipped by overnight delivery to the project laboratory. Sample custody and document control procedures are outlined in Section 4.

3. Quality Control Sampling

3.1 General

The following types of field QC samples will be collected for laboratory chemical analysis during groundwater sampling:

- Trip blank samples;
- Field duplicate samples.

Each type of field QC sample for laboratory chemical analysis is discussed below.

3.2 Trip Blank Samples

Trip blank samples will be used to determine if the sample shipping or storage procedures have influenced the analytical results. Trip blanks will be prepared by the project laboratory using deionized water and preservative and will be sent to the Site in the shipping container(s) designated for the project. These samples will be kept with the investigative samples and then shipped back to the project laboratory for analysis with the investigative samples. Trip blank samples will not be opened by sampling personnel.

Trip blanks will be analyzed for VOCs only. One trip blank will be submitted for each cooler containing groundwater samples for VOC analysis.

3.3 Field Duplicate Samples

Field duplicate samples will be collected and submitted to the project laboratory. Each duplicate sample will be collected immediately following collection of the parent sample, into a second set of laboratory-supplied containers. One field duplicate sample will be collected for each ten or fewer investigative samples submitted.

3.4 Matrix Spike/Matrix Spike Duplicate Samples

MS/MSD sample volumes are additional sample aliquots provided to the project laboratory to evaluate the accuracy and precision of the sample preparation and analysis technique. No discrete samples will be collected for MS/MSD analysis. Instead, the laboratory will select samples for MS/MSD analysis in accordance with their quality manual and in accordance with analytical method and laboratory procedure requirements.

4. Sample Custody and Document Control

4.1 Sample Numbering

Each sample container will be labeled with a unique sample number that will facilitate tracking and cross-referencing of sample information and will be recorded in the field logbook. The unique sample number will be recorded with the sample location in the field logbook at the time of sample collection. The field logbook will form part of the permanent field record. The sample numbering system to be used is described as follows (the information entered on the sample labels will be printed by the field sampler):

For VAP samples:

Example: VAP-N-MMDDYY

Where:

N - designates sequential number for each sample; and

MMDDYY - designates date of collection presented as month, day, year.

For monitoring well samples:

Example: LOC-XX-MMDDYY

Where:

LOC - designates sample location (*i.e.*, AMW-7D, etc.);

XX - designates types of sample (GW-groundwater); and

MMDDYY - designates date of collection presented as month, day, year.

QC samples also will be numbered with a unique sample number. The sample location of each QC sample will be recorded in the field logbook only. The sample numbering system to be used for such samples is described as follows (the information entered on the sample labels will be printed by the field sampler):

Example:

TB-MMDDYY-N

Where:

TB	-	designates type of field QC sample (Dup – field duplicate, TB – trip blank)
MMDDYY	-	designates date of collection presented as month, day, year; and
N	-	designates sequential number for each sample.

An example of the sample label is provided in Attachment 2.

4.2 Field Chain-Of-Custody and Documentation Procedures

The sample packaging and shipment procedures summarized below will insure that the samples will arrive at the project laboratory with the chain-of-custody intact. The Field Quality Assurance (QA) Officer will be responsible for oversight of field documentation procedures. An ARCADIS SOP for maintaining chain of custody is included in Attachment 1.

4.2.1 Field Procedures

1. The field sampler is personally responsible for the care and custody of the samples until they are transferred to another individual or properly dispatched to the laboratory. As few people as possible should handle the samples.
2. All containers will be labeled with unique sample numbers.
3. Sample labels will be completed for each sample using waterproof ink.

4.2.2 Field Logbooks/Documentation

Field logbooks will provide the means for recording data collection activities. As such, entries will be described in as much detail as possible so that persons going to the Site may reconstruct a particular situation without reliance upon memory.

Field logbooks will be bound field survey books or notebooks. Logbooks will be assigned to field personnel and will be stored in the ARCADIS Chicago, Illinois office when not in use. Each logbook will be identified by a project-specific number, which includes the project number.

The title page of each logbook will contain the following:

- Person to whom or task for which the logbook is assigned;
- Project number;
- Project name;
- The starting date for entries into the logbook; and
- The ending date for entries into the logbook.

Entries into the logbook will contain a variety of information. At the beginning of each day's logbook entry, the date, start time, weather, names of all sampling team members present, and the signature of the person making the entry will be entered. The names of individuals visiting the Site or field sampling team and the purpose of their visit will also be recorded in the field logbook.

All field measurements taken and samples collected will be recorded. All logbook entries will be recorded in ink, signed, and dated. If an incorrect logbook entry is made, the incorrect information will be crossed out with a single strike mark, which is initialed and dated by the person making the erroneous entry. The correct information will be entered into the logbook adjacent to the original entry.

Whenever a sample is collected or a measurement is made, a detailed description of the location will be recorded in the logbook. Photographs taken at a location, if any, will also be noted in the logbook. All equipment used to obtain field measurements will be recorded in the field logbook. The sample numbering system (as described in Section 4.1) will be recorded in the field logbook correlating the unique sample number to the sample location and sample depth (if necessary). In addition, the calibration data for all field measurement equipment will be recorded in the field logbook.

Samples will be collected following the sampling procedures documented in this FSP. The equipment used to collect samples, time of sample collection, sample description, and volume and number of containers will be recorded in the field logbook.

4.2.3 Transfer of Custody and Shipment Procedures

The sample packaging and shipping procedures summarized below will ensure that the samples arrive at the project laboratory with the chain-of-custody intact.

1. The field sampler is personally responsible for the care and custody of the samples until they are transferred to another person (*e.g.* shipping agent) or the project laboratory. As few people as possible will handle the samples.
2. All sample containers will be identified using sample labels, which will include the date of collection, unique sample number, and analyses to be performed.
3. Sample labels will be completed for each sample using waterproof ink.
4. Samples will be placed in coolers containing ice immediately after collection.
5. Samples will be accompanied by a properly completed chain-of-custody form. An example chain-of-custody form is provided in Attachment 2. The sample identification numbers will be listed on the chain-of-custody form. When transferring the possession of samples, the individuals relinquishing and receiving the samples will sign and record the date and time on the form. The chain-of-custody form documents sample custody transfers from the sampler to another person, to the laboratory, or to/from a secure storage area.
6. All sample shipments will be accompanied by the chain-of-custody form identifying its contents. The sampling team, after signing and relinquishing custody to the shipping agent, will retain the bottom (pink) copy of the three-part carbonless form. The project laboratory retains the yellow copy and the fully executed top copy will be returned to ARCADIS by the project laboratory as part of the data deliverables package.
7. Samples will be properly packaged for shipment and dispatched to the project laboratory for analysis with the signed chain-of-custody form enclosed in and secured to the inside top of each shipping cooler. Shipping coolers will be secured with custody seal tape for shipment to the laboratory. The custody tape is then covered with clear plastic tape to prevent accidental damage to the custody tape. An example chain-of-custody seal is provided in Attachment 2.
8. If the samples are sent by common carrier, a bill of lading will be used and copies will be retained as permanent documentation. Commercial carriers are not required to sign the chain-of-custody form as long as the form is sealed inside the sample cooler and the custody tape remains intact.

9. If samples are not shipped to the project laboratory the same day the samples are collected in the field, additional ice will be placed in the coolers, the coolers will be sealed and kept in a designated secure area until they are shipped to the project laboratory as described above.

4.3 Laboratory Chain-Of-Custody Procedures

Laboratory sample custody begins when the samples are received at the project laboratory. The laboratory's sample custodian will assign a unique laboratory sample identification number to each incoming sample. The field sample identification numbers, laboratory sample identification numbers, date and time of sample collection, date and time of sample receipt, and requested analyses will be entered into the sample receiving log. The laboratory's sample log-in, custody, and document control procedures are detailed in the QAPP.

4.4 Laboratory Storage of Samples

Following log-in, all samples will be stored at the project laboratory within an access-controlled location and will be properly maintained until completion of all laboratory analyses. Unused sample aliquots and sample extracts will be properly maintained for a minimum of 30 days following receipt of the final laboratory report by ARCADIS. The project laboratory will be responsible for the disposal of unused sample aliquots, samples, containers, and sample extracts in accordance with applicable local, state, and federal regulations.

The project laboratory will be responsible for maintaining analytical logbooks and laboratory data. Raw laboratory data files will be inventoried and maintained by the project laboratory for a minimum period of five years, after which time ARCADIS will advise the laboratory regarding the need for additional storage.

5. Field Calibration, Preventative Maintenance, and Standard Operating Procedures

Field calibration, preventative maintenance, and SOPs for field equipment are described in the following sections. Equipment calibration, maintenance, and inspections will be noted in the field log book.

5.1 Water Level Indicator

Water level measurements will be collected using a Solinst Model 101 water level indicator, or equivalent. These instruments do not require calibration. The only maintenance required is battery replacement. Battery replacement will be conducted on an as-needed basis, and the instrument will be inspected daily for signs of wear or damage.

5.2 Water Quality Meter

pH, temperature, conductivity, and ORP will be measured using a YSI Model 3560 instrument, or equivalent. The instrument will be calibrated daily, or if malfunction is suspected. Calibration will be performed in accordance with manufacturer's requirements.

5.3 Hydraulic Profiling Tool

The HPT will be calibrated by the subcontractors prior to the investigation. If possible, the first HPT boring should be completed in the vicinity of a continuously sampled and logged soil boring where there is reasonable confidence in the logged lithology. If beginning near an existing boring is impractical, a calibration boring shall be completed adjacent to the first HPT boring to provide a lithologic correlation to the HPT response curve. This comparison serves as a method of calibration.

6. Equipment Cleaning Protocols

Equipment used in sampling activities that contacts soil or groundwater will be decontaminated after completion of sampling at each location. Decontamination procedures are presented below, and a detailed SOP for equipment decontamination is also presented in Attachment 1.

6.1 Drilling Equipment Decontamination Procedures

Down-hole drilling equipment, such as drilling rods, augers, and soil samplers, will be decontaminated after each use using a three-step process as described below.

1. Wash the equipment with potable water to dislodge soil adhered to the equipment.
2. Wash with laboratory-grade detergent solution (Alconox or equivalent).
3. Rinse with potable water.

6.2 Down-Well Equipment Decontamination Procedures

Down-well equipment, such as water level indicators, will be decontaminated after each use using a three-step process as described below.

1. Wash the equipment with potable water.
2. Wash with laboratory-grade detergent solution (Alconox or equivalent).
3. Rinse with potable water.

If submersible pumps are used during well development, groundwater sampling, or other investigative activities, the following procedure will be used for decontamination after each use:

1. Wash the exterior of the pump and leads or cables with potable water.
2. Wash the exterior of the pump and leads with laboratory-grade detergent solution (Alconox or equivalent).
3. Rinse the exterior of the pump and leads with potable water.
4. Flush laboratory-grade detergent solution through the pump by immersing the pump in the solution, without tubing attached, and turning the pump on.

5. Flush potable water solution through the pump by immersing the pump in the solution, without tubing attached, and turning the pump on.

7. Management of Investigation-Derived Waste

The investigation-derived waste materials that are expected to be produced during the sampling and investigation activities include soil cuttings, decontamination water, well development and purge water, used personal protective equipment (PPE), and used disposable sampling equipment.

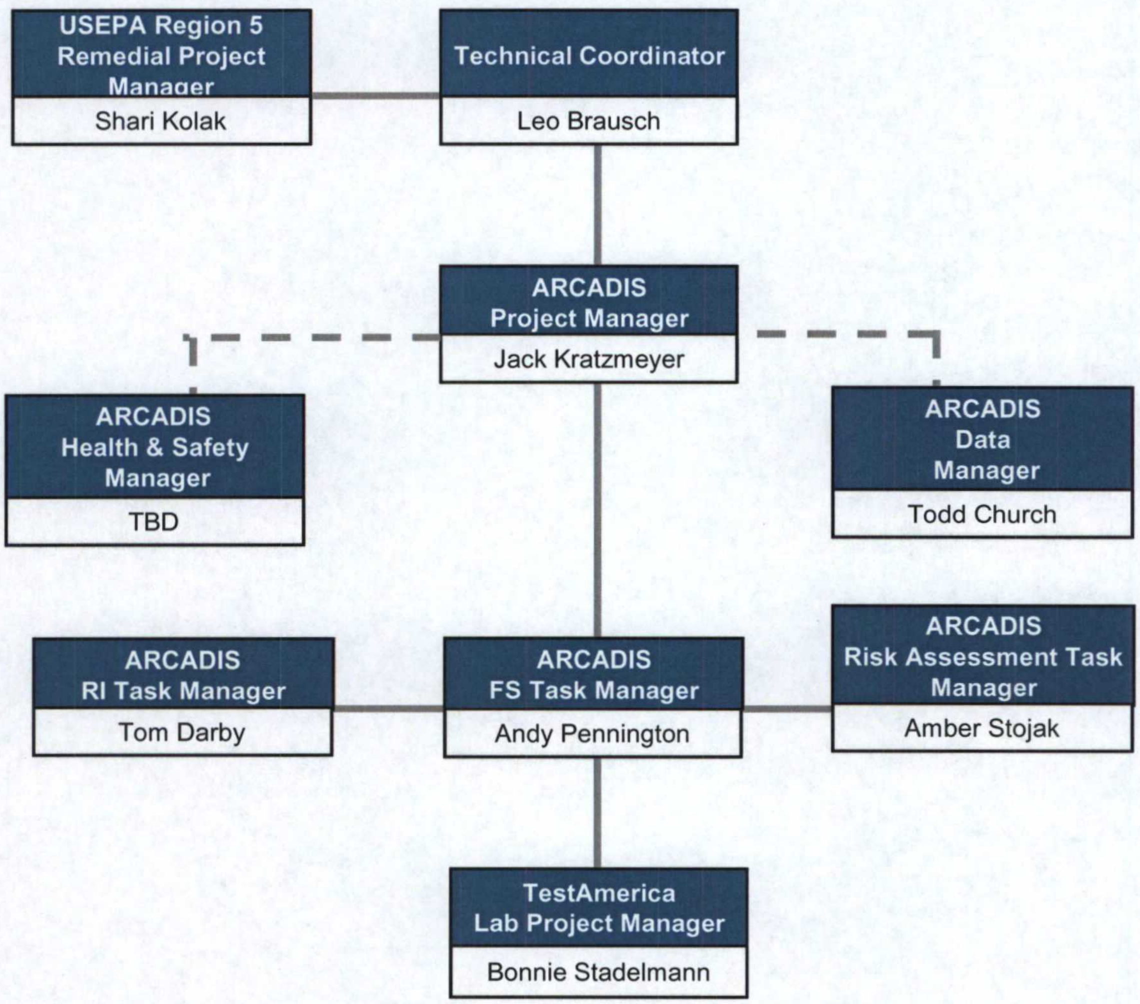
Well development water, purge water and decontamination water will be containerized in new or reconditioned Department of Transportation (DOT)-approved drums. A sample of the containerized water will be analyzed for VOCs by the project laboratory during the initial groundwater sampling event to determine the appropriate disposal procedures.

Soil cuttings will be containerized in new or reconditioned DOT-approved drums. A sample will be analyzed by the project laboratory to determine the appropriate disposal procedures.

Used PPE and single-use disposable sampling equipment (such as tubing) will be placed in garbage bags and will be disposed of at a sanitary landfill.

FIGURES

Figure 1. Project Management Organization Chart
Lake Calumet Cluster Site



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LEGEND

- PROPOSED SHALLOW PIEZOMETER
- PROPOSED DEEP PIEZOMETER
- PROPOSED HPT/VAP LOCATION
- LAKE CALUMET CLUSTER SITE BOUNDARY

Service Layer Credits: Sources: Esri, DeLorme, NAVTEQ, USGS, Intermap, iPC, NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, 2013

LAKE CALUMET CLUSTER SITE
CHICAGO, ILLINOIS

PROPOSED PIEZOMETER AND HPT/VAP BORING LOCATIONS

ARCADIS

FIGURE
2

ATTACHMENTS

ARCADIS

Attachment 1

ARCADIS Standard Operating Procedures

ARCADIS

Infrastructure · Water · Environment · Buildings

Imagine the result

Procedures for Use of the Geoprobe Hydraulic Profiling Tool® (HPT)

Rev. #: 0

Rev Date: February 2013

Approval Signatures

Prepared by: ______________________ Date: 2/11/13

Patrick Curry, C.P.G.

Reviewed by: ______________________ Date: 2/11/13

Joseph A. Quinnan, P.E., P.G.

I. Introduction

This document is the ARCADIS standard operating procedure (SOP) for collecting and analyzing data with the Geoprobe® Hydraulic Profiling Tool (HPT). The general principles of the tool operation are described, as are the field procedures, post processing of the HPT data and general principles of data interpretation.

The HPT provides a continuous profile of relative soil permeability at the centimeter scale. The resulting profile can be used to correlate hydrogeologic units across a site and guide vertical aquifer profile (VAP) groundwater sampling. With knowledge of depositional setting, the HPT profiles can be used to infer hydrofacies and add geologic interpretation to guide interpolation between the soundings. The HPT is advanced through an unconsolidated aquifer using a standard direct push drilling rig. The HPT tool is attached to the end of a drill string and enables a continuous metered injection of small volumes of water (typically between 200 to 300 milliliters per minute) during advancement of the probe. At the same time, the fluid backpressure due to injection into the formation, as well as the flow rate, are measured and logged at a high frequency. After correcting for atmospheric and hydrostatic pressure effects, the flow and pressure data are plotted as relative hydraulic conductivity by recognizing that hydraulic conductivity (K) is proportional to flow divided by pressure (Q/P).

The HPT also includes a dipole that logs the electrical conductivity of the soil to assist with correlating stratigraphy between HPT borings. Increasing clay content may correspond to increasing electrical conductivity. The complete Geoprobe guidance document describing the use and utility of HPT is provided as Attachment 1. Other useful documents are provided on the Geoprobe website (http://geoprobe.com/hpt-technical-documents).

II. Application

The ability of the HPT to resolve relative permeability of soils, and achieve both the depth and sampling goals for a project, is governed by the geologic setting. With the introduction of the 8040 series Geoprobe, the depth capabilities of direct push drilling have been extended to 100 feet or more in some geologic settings. However, for sites that require characterization deeper than 100 feet it is recommended that the tooling be tested at the site and confirmed to achieve the target depth. The HPT is very effective when utilized in aquifers with units of contrasting permeability. Sites dominated by very low-K soils (clay) or very high-K soils (well sorted sands and gravels) will likely provide only a maximum or minimum undifferentiated pressure and flow response and are not well-suited for the application of HPT. The typical range of K that provides a distinctive HPT response is 10^{-4} to 10^{-2} centimeters per second (cm/sec). An example HPT raw data set, similar to one that would be provided in the field, is included as Attachment 2.

Figure 1. The HPT direct push tool. Electrical conductivity dipole is visible on the upper image; the bottom image depicts the HPT injection port.

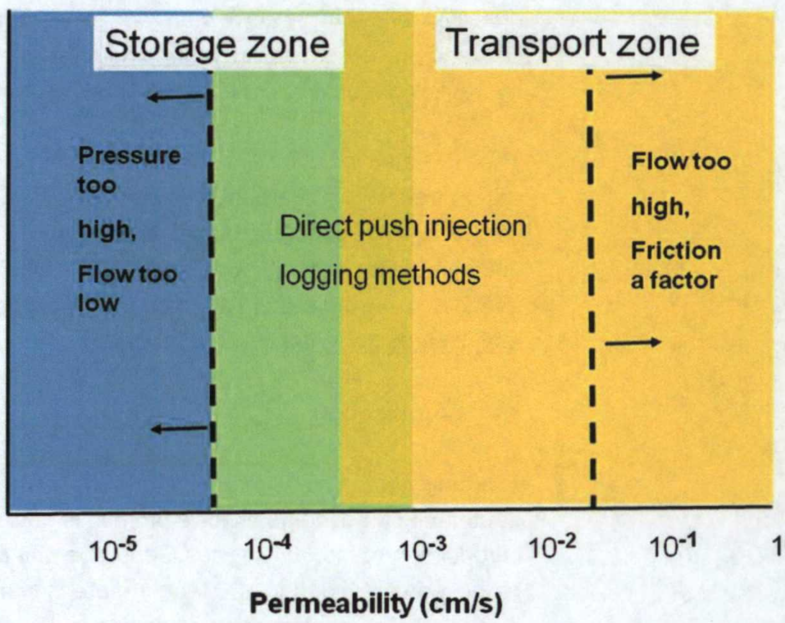


Figure 2. Range of hydraulic conductivity (permeability) that provides a unique response at standard injection rates.

III. Personnel Qualifications

Oversight of HPT drilling shall be provided by an experienced geologist that is familiar with the general principals of hydrogeology. Analysis and post processing of the HPT data is most effectively completed in Microsoft Excel. Review of the final post-processed HPT curves shall be provided by a senior geologist familiar with the application of HPT.

IV. Equipment List

The advantage of drilling with HPT is the ability to communicate the boring results to the project team in near real-time. The project team can then collaborate on the decisions (such as what intervals to groundwater sample) and modify the work plan as needed to best accomplish the goals of the investigation. Therefore, unlike traditional drilling methods, the only equipment required of the field personnel is that which facilitates preparation and transmittal of the HPT data, including:

- Field Book
- Laptop computer
- Satellite Internet “Air-Card”
- The Geoprobe DI Viewer® software package
- USB Thumb drive
- Cellular Phone

V. Cautions

Prior to beginning field work, the ARCADIS utility clearance policy must be review and implemented. The ARCADIS utility clearance policy is outlined on the Health and Safety Team Site (http://apex/HS/Pages/default.aspx).

The amount of water added to a given aquifer by the HPT is very small (typically 200-300 ml/min at an average drilling of 2 centimeters per second); however, if desired or required, fluorescein dye can be added to HPT injection water and monitored for during follow-up groundwater sampling. In this case, the project team must consult with an in-house tracer testing expert regarding the appropriate use of tracers. The general use of tracers to track drilling fluids is summarized in the *Use of Visible Tracer in Drilling Fluid to Obtain Representative Groundwater Samples During Drilling* standard operating procedure (SOP) available on the ARCADIS Source website (http://thesource.arcadissource.com/env/TKI/us/SOP/Pages/default.aspx).

Grouting of HPT boreholes requires removing the HPT tooling, lowering a separate grout pipe to the same depth, and injecting grout during the removal of the grout pipe. Specifications of materials used for grouting will be selected to meet state and/or federal requirements, if any, as well as project quality objectives.

HPT should NOT be used at source zones on sites where dense non-aqueous phase liquid (DNAPL) is suspected. As HPT cannot detect potentially mobile DNAPL, it is recommended to use the methods in ARCADIS' DNAPL contingency plan, to avoid mobilization of DNAPL. The next generation of HPT includes a groundwater sampler (HPT-GW), which would enable biased sampling to detect and screen for DNAPL on top of potential lower-permeability units away from the source. However, the best approach in potential DNAPL sources involves continuous whole-core soil sampling with NAPL dye testing. Should DNAPL pools be encountered, it is necessary to stop and re-evaluate methods to be certain that mobilization does not occur. It is advisable to complete stratigraphic characterization away from potential DNAPL first, and then develop a systematic plan using permanent casing, or dual-tube methods with continuous bottom-up grouting.

VI. Health and Safety Considerations

Field activities associated with HPT drilling will be performed in accordance with a site-specific Health and Safety Plan (HASP), a copy of which will be present on site during all drilling activities.

VII. Procedures

Pre-Field Activities

Before completing an HPT investigation, the project team should review existing boring logs and have a general understanding of what to expect for HPT response. Whenever possible, the first HPT boring should be completed in the vicinity of an continuously sampled and logged soil boring where there is reasonable confidence in the logged lithology. If beginning an investigation near an existing boring is impractical, or if there are no pre-existing borings, a calibration boring shall be completed adjacent to the first HPT boring to provide a lithologic correlation to the HPT response curve. It is critical to account for the calibration process whenever planning to use HPT. Calibration soundings allow accurate interpretation of the HPT data, so they must be accounted for in project schedules and budgets. Soil description for the calibration boring should adhere to the *Soil Description* SOP located in The Source SOP catalog (http://thesource/env/SOP/Documents).

In general, the completion of HPT borings on a transect (or transects) at regularly spaced intervals provides the best results for aquifer characterization. Transects should be completed either perpendicular or parallel to groundwater flow within the groundwater plume or area of interest. This approach provides a high-resolution cross-section of hydrostratigraphic units controlling groundwater flow. The spacing and depth of the borings and the length of the transect should be selected based on the size of the plume or site, and the project goals and budget.

If HPT is to be used in combination with VAP sampling (or using HPT-GW), a provision should be made to complete measurements of absolute hydraulic conductivity for comparison to the HPT data. Hydraulic conductivity measurements could be based on sieve analysis, pneumatic slug testing of VAP intervals, or specific capacity testing during VAP interval pumping.

Communication

A clear line of communication between the geologist providing oversight and the HPT operator should be established prior to drilling. The monitor that provides the HPT readout should be positioned so as to be viewable by both the ARCADIS geologist and the drilling personnel. Following completion of the HPT drilling, the HPT data should be copied to a disc or thumb drive and transferred to the ARCADIS geologist's laptop for analysis and then emailed to the project team for discussion.

General HPT Drilling Methodology

The HPT is attached to a standard direct push drill string. The trunk line, supplying injection water and relaying information to and from the tool, is threaded through the drilling rods. Older versions of the HPT use the "Direct Viewer" monitor that has a small LCD readout showing the HPT response. Newer versions are connected directly to a laptop and the real-time information is displayed through the monitor. Setup of the HPT will be handled by the drilling subcontractor. Tooling string diagrams are provided as part of Attachment 1.

Before an HPT boring begins, pre-test calibration is performed to ensure the HPT pressure and EC responses are consistent with expected values. ARCADIS field staff should ensure this process is completed and documented in the field notes. The HPT is then advanced into the subsurface with the direct push rig at an average rate of 2 centimeters per second (cm/sec). The typical injection rate is 200-300 milliliters per minute (ml/min). Once below the water table a "dissipation test" should be completed to verify the elevation of the water table. During a dissipation test the drilling is paused and the HPT flow is turned off. The pressure response is then recorded as it returns to a stable reading consistent with ambient hydrostatic pressure. The dissipation test results can then be used post drilling to correct the HPT pressure curve for hydrostatic pressure effects. The test is also required for the Geoprobe DI Viewer® software to determine the "Estimated K" profile curve. It is recommended that dissipation tests be completed in a low pressure response region of the aquifer (corresponding to higher K soils) to expedite the return to static conditions. At least two dissipation tests should be completed per borehole; one within a relatively shallow portion of the aquifer and second test within a deeper interval of the aquifer near to the total depth of the boring. Note that the dissipation test should also be performed when confining or apparent confining units are encountered. Upon penetrating the underlying permeable unit, completing the test will enable assessment of vertical gradients, which can be used in framing the conceptual site model (CSM).

Following completion of the HPT boring, post-test calibration will be performed to verify HPT performance and quantify sensor "drift", if any, during borehole advancement. The HPT response data can be immediately transferred to the geologist laptop and viewed with the DI Viewer software. As mentioned above, a dissipation test is required for the DI Viewer software to determine an estimated K curve for the boring. The estimated K curve is essentially a Q/P curve corrected by an empirical relationship developed by Geoprobe between the HPT Q/P and correlated absolute K measurements primarily collected within the central US.

The DI Viewer estimated K profile should not be relied upon as an accurate indicator of absolute K, but rather viewed only as a first approximation of relative permeability. Post processing of the data can include a comparison of the Q/P curve to absolute hydraulic conductivity measurements collected from the site such as slug tests or sieve analysis. An example of a post-processed HPT log that includes a comparison of the HPT data to the logged geology and absolute K measurements is provided as Attachment 3.

The DI Viewer software can be used in the field to create a draft HPT log that can be sent to the project team for review. The logs can be set up to include various curves including the electrical conductivity response, pressure response, flow rate and the estimated K curve, if desired.

Post Processing of HPT Data

Post-processing of the raw HPT response data will be required if output other than the DI Viewer logs are required for project deliverables. As of the date of this SOP, the HPT data recorder produces three files that are required for post processing; a DAT file, an INF file and a DIS file. The DAT file contains all of pressure, flow and EC data recorded for a borehole. The INF file contains the date, time, name of the boring, calibration results and all of the header information needed to understand the DAT file. The DIS file contains the dissipation test data for the boring.

ARCADIS has developed multiple Microsoft Excel® templates for HPT data processing and analysis. Project teams should contact Triad Investigation Sub-Discipline team members to acquire example files and a general explanation of their use. The Triad page is available through the ARCADIS Source website (http://thesource.arcadissource.com/env/TKI/us/knowledgebase/Pages/default.aspx). In general, the HPT raw pressure data needs to be corrected for hydrostatic and atmospheric pressure effects. The hydrostatic correction is based on the static groundwater elevation at the boring location. Atmospheric effects can be estimated by determining the approximate barometric pressure during boring advancement.

Interpretation of the HPT data should be completed by a geologist familiar with the principles of hydrostratigraphy and hydrogeologic interpretation. Correlation of HPT response to geologic units should consider existing soil descriptions and nearby boring logs, as well as absolute K measurements completed during the HPT field activities.

VIII. Quality Assurance

Following the processing of the HPT data, a senior review should be completed by a geologist familiar with the operation and application of the HPT, and should include a thorough review of the HPT processing table and a review of the final logs.

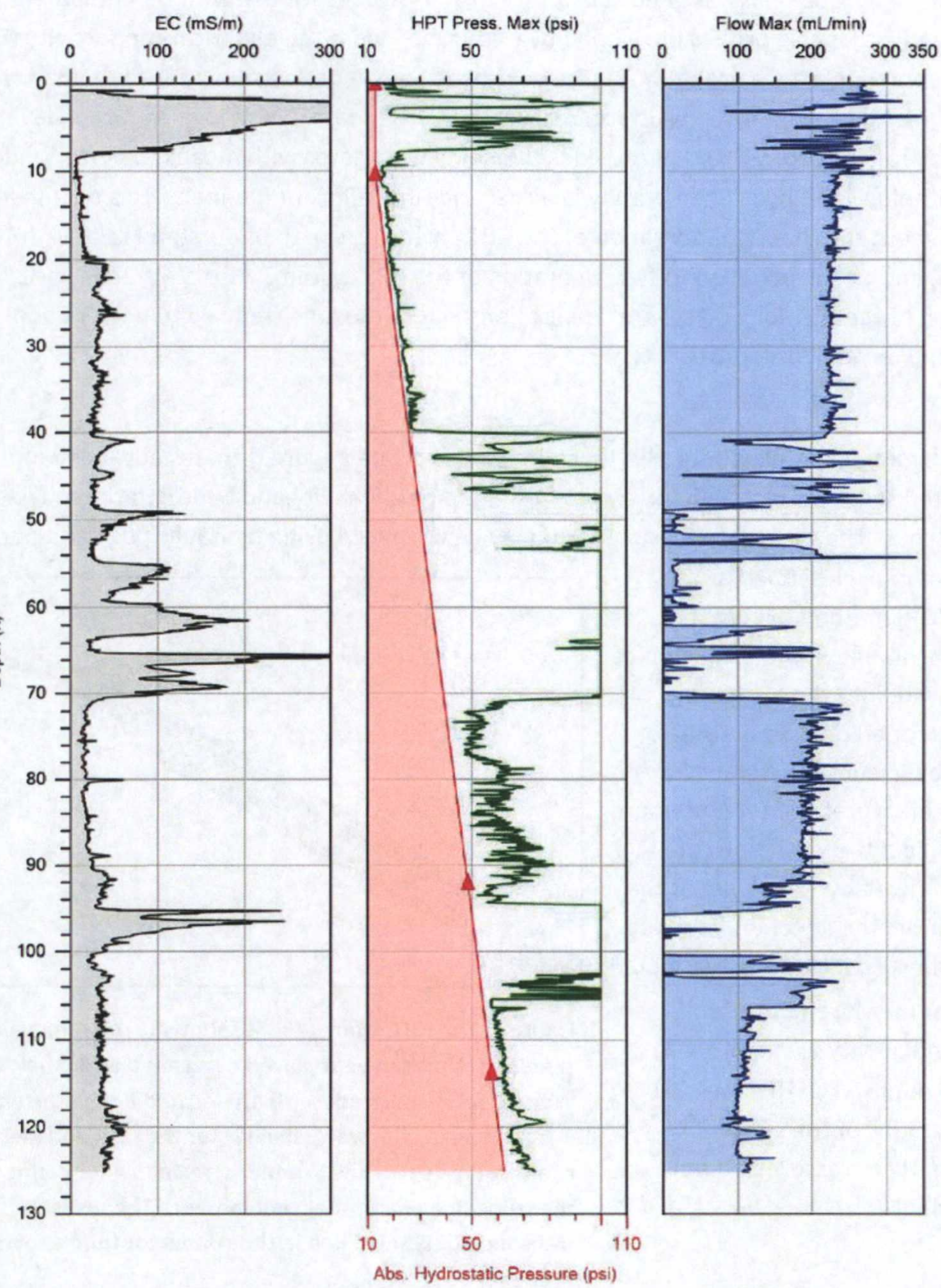
Attachment 1

Geoprobe HPT Guidance

Application of the Geoprobe® HPT Logging System For Geo-Environmental Investigations

Wes McCall, M.S., P.G.

Geoprobe® Technical Bulletin No. MK3184
Prepared: February, 2011



A typical HPT log displaying absolute hydrostatic pressure (shaded) over laying the HPT pressure on center graph. Hydrostatic pressure line is based on two dissipation tests run at 92ft and 113ft below grade.

Introduction

Direct push equipment and methods for subsurface investigation have become primary tools for the geotechnical and geo-environmental site investigator. The efficiency of the direct push (DP) technique for many basic investigation activities such as soil, groundwater and soil gas sampling have made it the method of choice for many sites where work is performed in unconsolidated soils and sediments. To improve efficiency, data density and the development of more accurate conceptual site models (CSM) Geoprobe® has designed subsurface logging probes for use with DP equipment and methods. The first logging probes developed by Geoprobe® were the electrical conductivity (EC) probe and the membrane interface probe (MIP). These probes helped define subsurface lithology and volatile contaminant distribution in the subsurface, respectively. The most recent logging probe developed is the hydraulic profiling tool (HPT) that provides the field investigator with means to better understand subsurface lithology and hydrostratigraphy in a cost and time efficient manner. This document provides information about the theory of operation of the HPT probe, its use to understand relative formation permeability, and an introduction to field operation of the HPT system. Also covered is basic interpretation of the HPT log and several applications where the logs are used to better understand the subsurface and develop accurate CSMs.

What is HPT ?

The hydraulic profiling tool (HPT) is a direct push probe (Figure1) that is advanced into unconsolidated soils and sediments to assess formation permeability and hydrostratigraphy at the centimeter-scale. The HPT probe is robust and may be advanced using hydraulic push and percussion probing, commonly described as the direct push (DP) method (Figure 2). During advancement water is injected at a controlled rate into the formation through a screened port on the side of the HPT probe (Figure 3). A transducer in the probe measures the total pressure required to inject the water into the formation while a flow controller at the surface monitors the injection flow rate. The HPT probe also includes a Wenner-type array for measurement of soil electrical conductivity as the probe is advanced to depth. The HPT log (Figure 4) provides graphs of the electrical conductance, HPT pressure and flow rate versus depth.

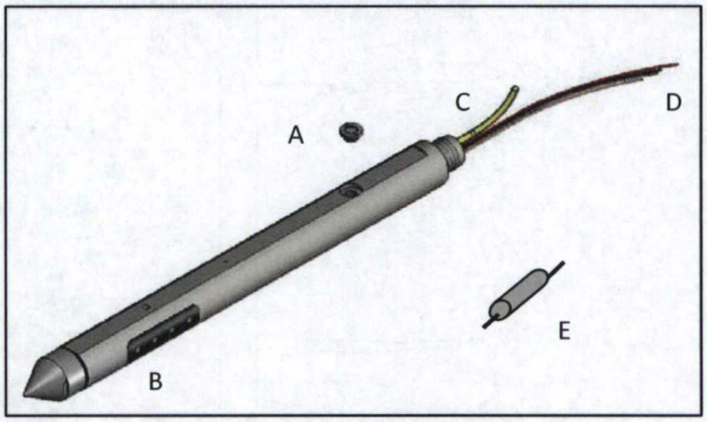
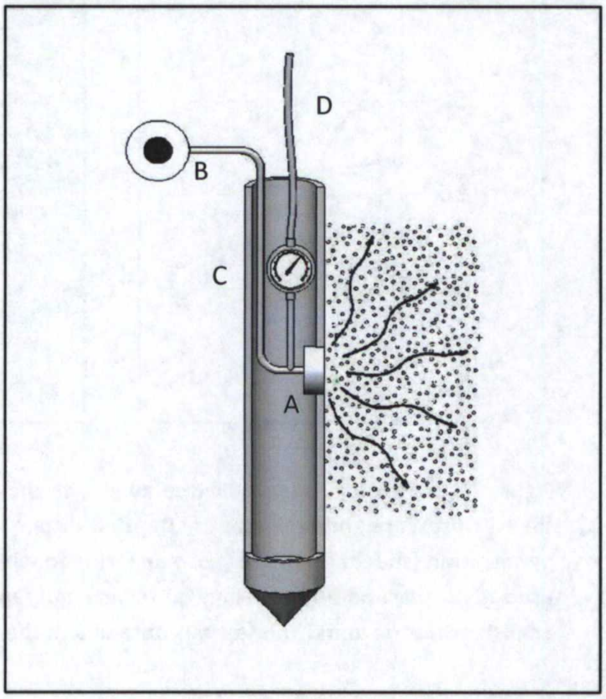


Figure 1: The HPT probe (K6050) showing the removable port-screen (A) that can be replaced or cleaned in the field. The EC Wenner array electrodes (B) are located below the water injection port. The water line (C) for the port and electrical connections (D) for the Wenner array allow for connection to the trunk-line and up-hole equipment. The pressure transducer (E) is installed in the connector tube above the probe for easy service access.

Figure 2: Operator setting up HPT Probe for advancement into the subsurface with a Geoprobe® 7822 machine. The HPT probe is advanced at 2cm/sec using the system hydraulics and probe hammer when required. Logs to a depth of approximately 60ft (20m) are usually completed in about one hour.

Figure 3: This illustrates injection of water from the HPT screened port (A) into a coarse granular formation. The water supply and pump are located up-hole (B) while the HPT pressure transducer (C) is located down-hole at the probe, and in-line with the fluid flow. The transducer measures the total pressure required to inject water into the formation. The pressure data from the transducer is transmitted up-hole via the trunk-line (D) to the field instrument and portable computer.



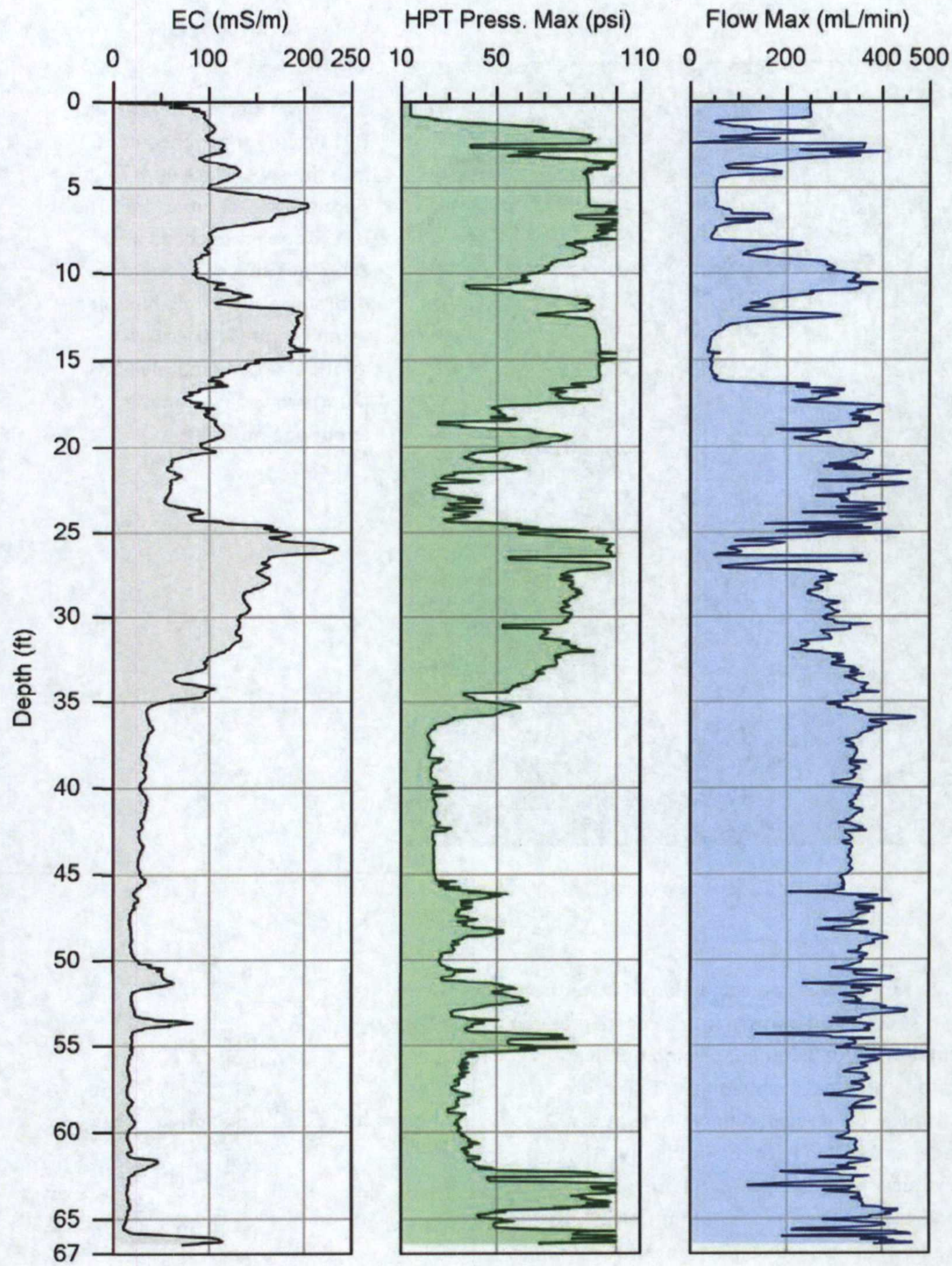


Figure 4: An HPT log as typically displayed with the electrical conductivity graph on the left followed by the HPT pressure and flow graphs. Depth is displayed along the vertical axis at left. The rate of penetration (speed) graph may also be included with the log if desired. The DI-Viewer® software is used to display and print the logs for review and reporting. The logs may be displayed with either English or metric units. This log was obtained in the alluvial deposits of the Smoky Hill River, Salina, KS.

Uses

The HPT logs may be used to support site investigation and remediation in a variety of ways. Some applications of the HPT logs include:

- Determine lithology/hydrostratigraphy
- Qualitatively define formation permeability
- Locate contaminant migration pathways
- Identify optimal locations for monitoring and water supply well screens
- Guide remedial injection programs
- Construct Geologic cross-sections
- Locate and define brine plumes or seawater intrusion areas (when coupled with EC)
- Estimate local formation hydraulic conductivity

HPT logs also may be combined with membrane interface probe (MIP) logs to assist in determining how hydrostratigraphy influences or controls volatile contaminant distribution and migration. Several applications will be reviewed below.

Background

Several direct push (DP) logging methods have been developed for geotechnical, geological and environmental investigations for use in unconsolidated soils and sediments. The cone penetration test (CPT) has been in use for many years to conduct geotechnical and geo-environmental investigations (Robertson et al. 1992, Lunne et al. 1997). Geoprobe Systems introduced its first DP logging tool in 1994, an electrical conductivity probe, that has been widely used to evaluate soil and sediment lithology (Christy et al. 1994, EPA 2000, Schulmeister et al. 2004, Wilson et al. 2005). This was followed by the membrane interface probe (MIP) which has been effectively applied to track and map non-aqueous phase liquids (NAPL) and plumes of fuel hydrocarbons and chlorinated volatile organic compounds (X-VOC) in unconsolidated formations (Christy 1996, Griffin and Watson 2002, ASTM D7352).

As the environmental industry matured it became evident that more detailed data about formation permeability and hydraulic conductivity (K) was necessary to accurately evaluate the potential for contaminant migration and better assess human health risks at contaminated facilities (EPA 1998, ASTM E1739, ITRC 2008). Geoprobe initially developed the pneumatic slug test system (Geoprobe 2002, 2011, ASTM D7242) and field methods (Butler et al. 2002, McCall et al. 2002) that allowed investigators to measure K over discrete intervals using temporary groundwater sampling tools, direct push installed wells or conventional wells. However, the need for higher data density and greater time efficiency eventually lead to the development of permeability logging tools such as the Cone Permeameter™ (Geoprobe 2003, Butler et al. 2007), high resolution Piezocone (Kram et al. 2008, Elsworth and Lee 2007, Lee et al. 2008), the direct push injection logger (Dietrich et al. 2008, Liu et al. 2009), the high resolution K tool (Liu et al. 2009) and the HPT system (Geoprobe 2006a, 2007, 2010b). The HPT system provides the project manager with a log of injection pressure, water flow rate and electrical conductivity for the formation penetrated (Figure 4). These logs provide information about formation lithology and permeability at the centimeter-scale. An HPT log to a depth of about 60ft (20m) can be obtained in about one hour by an experienced two person field crew.

The HPT System and Basic Field Operation

In this section the primary components of the HPT system are introduced and described. Additional information on HPT tool configurations and system components with part numbers are provided in Appendix I. This section also outlines the basic procedures for running an HPT log and the primary quality assurance (QA) tests conducted in the field to verify that the HPT probe and system are operating properly.

HPT System Components

The primary down-hole component of the system is the HPT probe (Figure 1). Water is injected through a removable stainless steel mesh screen located on the side of the probe. The effective port diameter is approximately 0.30in. (7.6mm) and it is located above the EC Wenner array. This configuration assures that water injected from the port does not interfere with the measurement of bulk formation electrical conductivity. The pressure sensor is located in the connection tube in-line with the water supply and above the probe body for servicing access (Figure5). The trunk-line provides for electrical connections and a water supply line to the surface components of the HPT system. The trunk-line is pre-strung through the probe rods which are set up in a rack for easy handling and transportation (Figure 6).

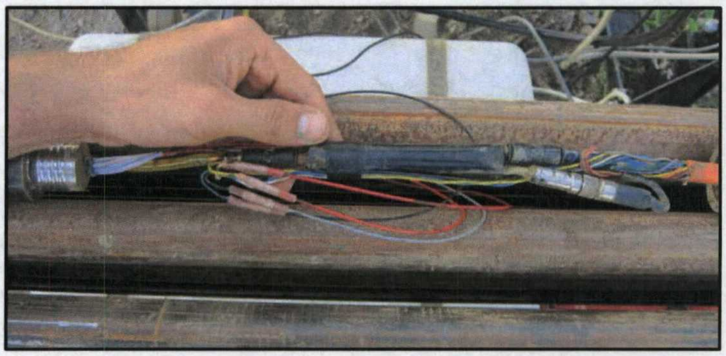


Figure 5: Checking transducer (in hand) and Wenner array connections prior to logging. These connections are made in the connection tube above the probe body for easy access to service.

The up-hole components of the HPT system include the HPT pump, flow controller, FI6000 field instrument and a lap top computer (Figure 7). The HPT pump has a maximum rated flow of 1000 ml/min. However, for logging operations flows are usually maintained in the 200ml/min to 300ml/min range. The flow controller provides connections for water flow from the pump to the trunk-line and monitors flow rate. Additionally, the controller enables the field operator to stop flows when dissipation tests are performed down-hole. The field instrument receives signal input from the string pot (depth encoder), flow controller, pressure sensor and Wenner array. That data is transferred in digital format from the field instrument to the operator's computer.

Figure 6: Probe rods are prestrung with the HPT trunkline and may be stored and transported on a Geoprobe® drop rack. In this setup the water tank, generator and instrumentation may be loaded on the rack for easy transportation on site.

An integral part of the HPT system is the DI acquisition software. The software is installed on the computer and permits the operator to view the log (Figure 7) as the probe is advanced into the subsurface with the Geoprobe® unit. The log and associated QA data are stored on the computer for later review, interpretation and reporting.

Figure 7: The HPT flow controller (center) receives water from the pump (right) and regulates flow to the probe. The FI 6000 Field Instrument (left) supplies conditioned current for the EC measurement, receives analog signal from the HPT probe and provides digital output to a lap top computer (top center).

QA Tests

Prior to running an HPT log the operator performs quality assurance tests on the pressure sensor and Wenner array. The results of the QA tests are saved in an information file for later review and reporting (Appendix II). Initially, the Wenner Array electrodes are placed on a test jig and the test load (Figure 8) is used to verify the electrical continuity and isolation of the EC system. Next, a reference test is performed on the pressure sensor. This is accomplished by submerging the HPT probe a specified depth below the water level in a reference tube (Figure 9). A two step test enables the operator to verify that the pressure sensor is providing the correct measurement (0.216 psi/1.49kPa) for a defined length (6 inches/15.2cm) of water column. If the result is more than ±10% out of range the transducer fails the QA test. Occasionally, the HPT screen becomes clogged or damaged and must be removed and cleaned or replaced to obtain a successful QA test.

Figure 8: As part of the field QA testing the EC probe is setup in the test jig (bottom) and the EC test load (top) is used to verify the performance of the EC array before each log is run. The QA results are saved in the information file (Appendix II).

Figure 9: The HPT probe is inserted in the reference tube to verify performance of the pressure transducer as a part of the pre-log QA testing protocol. The QA test provides a pass/fail report for the transducer with a know height of water column. Reference tests are saved in the information file for each log (Appendix II).

HPT Logging

After the QA test is completed the HPT probe is placed beneath the probe hammer (Figure 2) with a slotted drive cap installed. The probe is set with the HPT port at the ground surface to start the logging process. Using the hydraulics and probe hammer the operator advances the probe at a rate of 2cm/sec (0.8in/sec) into the formation. The string pot is mounted on the probe mast and accurately tracks depth as the probe is advanced. The log is visible onscreen as the probe is advanced (figure 7).

Once the probe is below the static water level the investigator may select an appropriate interval to perform a dissipation test. Dissipation tests are best run in coarser grained materials (sand ± gravel) to assure that the local ambient hydrostatic pressure is measured quickly and accurately. The time versus pressure log (Figure 10) of a dissipation test is later used to determine the local static water level and hydrostatic pressure profile at the logged location. Dissipation tests will be covered in more detail in following sections.

After the log is advanced to the maximum desired depth the operator uses the probe hydraulics and rod grip system to extract the probe rods and HPT probe. It is important to maintain flow through the HPT port as the probe is extracted to prevent clogging and potential damage to the HPT pressure sensor. Once the probe is extracted another QA test is performed to verify probe performance during the log and for later logging operations. The HPT log and QA tests are saved by the DI Acquisition software for later review and reporting.

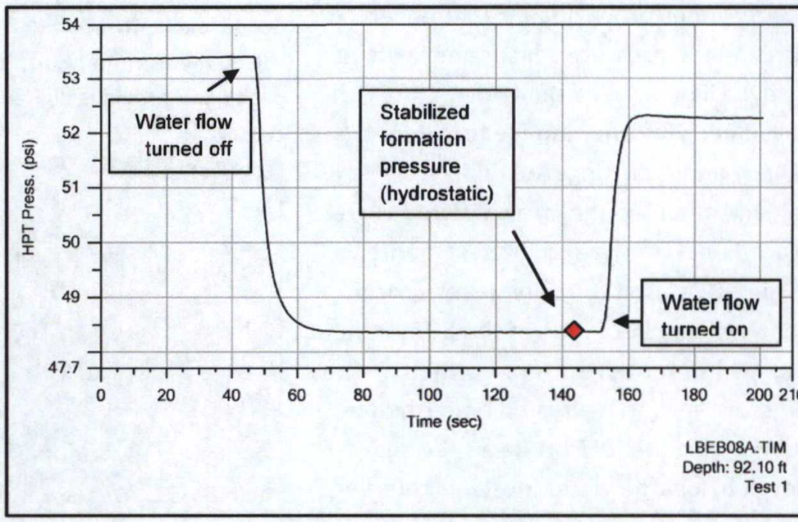


Figure10 : Time log of a pressure dissipation test performed at a depth of 92.1 ft (28.1 m) below grade in Halstead, KS. The diamond label on the graph corresponds with the stabilized pressure (48.37 psi/ 333.8 kPa) for this test. This pressure is used to calculate the local water level and may be used to calculate the hydrostatic pressure profile for the tested location.

Review and Interpretation of HPT Logs

To review an HPT log after it has been completed the DI Viewer software package is used. The DI Viewer software may be downloaded at www.geoprobe-di.com. The DI Viewer software displays the three primary components of the HPT log in the default setting (Figure 4). The three components are (l to r) electrical conductivity, HPT pressure, and flow rate. The graph for rate of penetration may be added to the log if desired. The software also provides for viewing of dissipation tests and calculation and plotting of the hydrostatic pressure trend line, corrected HPT pressure and an estimated K log (hydraulic conductivity). In addition, the software can be used to compare 2 or more logs in overlays and multiple pressure logs or EC logs can be plotted side-by-side to generate basic geologic cross-sections. Several of the software features will be used in the following discussion of log interpretation.

The HPT probe is advanced into the subsurface using direct push (DP) methods. Thus, the probe is in intimate contact with the formation materials being penetrated. The DP logging method simplifies log interpretation in several respects as compared to traditional open borehole or down well logging. In borehole and well logging the boring diameter, borehole fluid composition, drilling fluids, gravel packs, grouts and well casing may influence the log response (Keys 1997) and so need to be considered during interpretation, none of these factors are involved in DP log interpretation.

(The following discussion of HPT log interpretation will be based on the log in Figure 4 unless otherwise noted)

Electrical Conductivity

Geoprobe has been providing Wenner and dipole electrical conductivity (EC) logging tools for sometime before the HPT probe was developed (Christy et al. 1994). Interpretation of the electrical conductivity (EC) log will be reviewed briefly here and then its use in combination with the HPT pressure log discussed in the following section. Additional information is available from several sources regarding electrical log interpretation (Christy et al. 1994, Schulmeister et al. 2003, Keys 1997, Dobrin 1976). The general rule for interpretation of EC logs in soils and sediments containing fresh water is that increasing clay content results in higher electrical conductance of the bulk formation. More detailed information on EC log interpretation follows.

The bulk electrical conductivity of unconsolidated soils and sediments is influenced by several factors. The primary factors include grain size, mineralogy, moisture content, the presence of dissolved ions in contained groundwater, and temperature (Keys 1997). In granular soils and sediments the clays usually exhibit higher electrical conductance than silts, sands, and gravels (Christy et al. 1994, Schulmeister et al. 2003, Wilson et al. 2005). The EC of clay rich sediments often ranges between 50 mS/m to 200+ mS/m, generally increasing with higher clay content (5-8ft, 12-15ft, 25-33ft). The electrical conductance of clays is related to their mineralogy and soils developed in humid regions (e.g. southeastern U.S.) often have clays with lower electrical conductance. Dry, clean sands and silts comprised primarily of quartz will have very low EC, often less than 1 to 2 mS/m. When clean sands are saturated with groundwater the bulk EC of the material will be largely due to the EC of the contained groundwater (35-50ft). As the dissolved solids and ions content of the groundwater increases the EC of the bulk formation also will increase. It is recommended that targeted soil sampling be conducted to verify log interpretation, especially at a new field site where limited or no previous soil boring data is available.

The EC of pure distilled water is very low, approaching 0.005 mS/m (USGS 1992), but a small amount of dissolved ions in the water will increase its EC notably. When electrically active salts (e.g. sodium chloride/NaCl) are dissolved in water the EC of the solution will increase significantly (Keys 1997). As a reference point, the EC of ocean water is approximately 5,000 mS/m (USGS 1992). However the EC of beach sand consisting largely of quartz and saturated with ocean water will be notably less than 5,000 mS/m due to the insulating properties of the sand matrix. Still, the presence of sea water (or brine) in a formation will generally overshadow the EC variation due to the formation solids making it difficult if not impossible to interpret formation variability (e.g. clay – silt – sand content) based solely on the EC log. However, the HPT pressure log can provide information on formation permeability and lithology even when the contained groundwater has elevated salt content.

HPT Pressure

The HPT pressure log often reveals a wide range in observed pressure (Figure 4) depending on the characteristics of the soil or sediment penetrated. From Darcy's Law we know that flow (Q) is proportional to the change in head (pressure) across a column of sediment with a given permeability (Fetter 1994). For this same sediment, as the pressure increases the flow will increase, within reasonable limits. From this relationship it is apparent that higher pressure resulting from the injection of water into a sediment at a given flow rate indicates lower permeability and conversely, that lower pressure from injection of water at a given flow rate indicates higher permeability. It is this simple relationship that allows the investigator to evaluate changes in relative permeability of soils and sediments in an HPT log by reviewing the pressure verses depth log .

Reviewing the pressure and EC logs(Figure 4) it is apparent that higher EC in general correlates with higher pressure down the log. So as increased EC generally indicates increased clay content, increased pressure generally indicates lower permeability (e.g. 13-16ft). Conversely, lower EC suggests increased sand and gravel content and lower pressure indicates higher permeability (e.g. 35-45ft). Based on this the EC and pressure log indicates that the upper 35 feet at this location consists primarily of clay rich sediments, where zones of lower EC and lower pressure indicate increasing silt and sand content. Repeated sampling at a depth of 22 to 24 feet at this site has produced wet sandy silt with clay and is the shallowest zone where groundwater can be sampled locally. This correlates nicely with the relatively lower EC in this zone as compared to the surrounding materials.

Between approximately 35-45ft at this site, the EC and pressure are relatively low and the log suggests the formation consists largely of sand ± gravel across this interval. Groundwater sampling tools installed at several locations across the site in this interval produced abundant water. Pneumatic slug tests of screened intervals in this zone provided hydraulic conductivity values ranging from about 35ft/day to 60ft/day (1.25E-2 cm/s to 2.10E-2 cm/s), consistent with sand ± gravel aquifer materials. Additionally, soil cores collected over this interval consisted primarily of saturated sand with some fine to medium gravel and minor silt ± clay.

Between approximately 45-50ft in this log the EC is generally low with a few peaks of slightly higher EC below this interval suggesting the presence of inreased clay content (e.g. clay rich lenses). The HPT log over this same interval reveals several elevated pressure peaks, roughly corresponding to the depths of the EC peaks. It is important to note that the relatively large pressure peaks across this zone indicate some significant decreases in permeability interspersed with higher permeability layers. The decreases in permeability indicated by the large pressure peaks below 45ft are greater than may have been anticipated based solely on the small EC spikes observed. Soil sampling across this interval produced sand ± gravel interspersed with discontinuous gray colored silty-clay layers. Under some groundwater settings cations may be leached from clays. This can result in fine grained layers with lower electrical conductivity than generally encountered, as seen here.

One important feature to recognize on this log occurs across the 45-50ft interval. Here the EC is consistently low, conversely the HPT pressure increases up to 50+psi in this interval. This relationship is just the inverse of what is normally expected. Across this interval the speed of penetration consistently decreases and the probe hammer is run at higher frequency to penetrate this denser material. Sampling has shown that calcium carbonate cementing has occurred sporadically over this depth interval. The calcium carbonate cement would decrease the permeability locally. Other conditions may also yield low EC and relatively high HPT pressures. Some of these conditions include dilatant sands, silt layers with low clay content, and the cementing discussed here.

A drop in EC across a narrow interval corresponding with a drop in HPT pressure would indicate a sandy layer bounded by finer grained materials (22-24ft, 64-66ft). Sometimes HPT pressure may drop briefly while EC remains high (e.g. 27ft). This occasionally can occur when probe advancement is stopped to add the next drive rod. Here the flow continues from the port while the probe is stationary. This can result in the applied HPT pressure exceeding the local lithostatic pressure and fracturing or channeling of the formation, resulting in anomalously low observed pressure. Fracturing of the formation could occur as the probe is being advanced when the injection pressure momentarily exceeds the local lithostatic pressure. A plot of the effective pressure verses depth over the HPT pressure log can indicate where such conditions could occur. Targeted soil sampling may be required to verify the character of formation materials over intervals where anomalous pressure and EC results occur.

HPT Log QC and Overlays

The primary method to confirm the validity of HPT logs is to collect targeted soil samples across intervals of interest. An effective way to perform the sampling would be to use DP soil sampling tools such as the MC5 system (Geoprobe 2006b, ASTM D5282). The investigator may choose intervals for sampling that are of particular importance to the purpose of the investigation. For example, is an aerially extensive layer defined by high EC and high pressure (25-30ft) actually low-permeability clay that will provide an effective barrier to downward migration of contaminants? Alternatively, is a low EC and low pressure layer across the site (35-45ft) clean sand that could behave as a preferential migration pathway for contaminants? Or a productive zone for a residential water well? An option to evaluate the sand layer would be to install a temporary DP groundwater sampling device such as the SP16 or SP22 (Geoprobe 2006c, 2010a, ASTM D6001) and perform pneumatic slug tests (Geoprobe 2011, ASTM D7242).

Another approach to perform HPT log and system QC is to run a replicate log 2 to 3 ft (0.5 to 1 m) from the original log location. The DI Viewer software is used to overlay the original and replicate logs for comparison (Figure 11). While natural heterogeneity in a formation will result in some differences between the logs, the overall trends and major features will normally correspond very well as observed here. Some differences are notable below about 50ft in these two logs. However, several samples from this depth interval found that clay layers varied locally in thickness and were discontinuous over small lateral distances.

Determining Local Static Water Level and Piezometric Heads

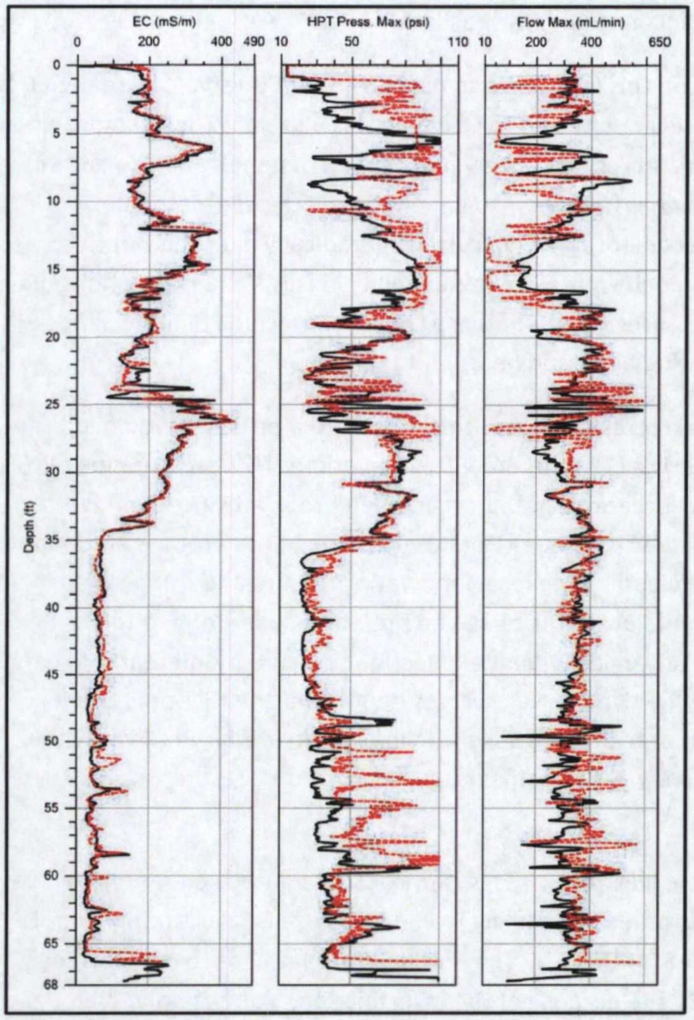


Figure11 : One method of quality control in the field is to perform a replicate log at about 2 to 3 ft (0.5 to 1 m) from the original location. The replicate logs here show good repeatability for the large scale EC, pressure and flow features. Small scale variations are expected due to the heterogeneity that occurs in natural sediments.

Another important feature of the HPT pressure log is the increase in hydrostatic pressure as the probe is advanced below the local water level (Figure 12). The increase in hydrostatic pressure results in a "rising baseline" on the pressure log. A simple interpretation may be used in the field to estimate the local water level by visually estimating where this "baseline" intersects atmospheric pressure, on this log at about 10ft below grade (Note: nominal atm. P =14.7psi/101.4kPa at sea level). To obtain a quantitative determination of the local static water level a pressure dissipation test must be performed during the logging operation. As discussed above it is most efficient to perform dissipation tests in coarser grained materials, as the pressure will dissipate rapidly. To perform the dissipation test the advancement of the probe is halted and the field operator then starts a time log (Figure 10). Water flow is turned off to observe and record the dissipation of the HPT pressure verses time, until pressure stabilizes. The stabilized pressure is the absolute hydrostatic pressure at the depth of the test. Knowing the depth of the test, the absolute hydrostatic pressure and the atmospheric pressure the static water level may be calculated (Table 1).

Hydrostatic pressure may not always increase linearly with depth. Multiple dissipation tests may be performed at different depths during a single log to evaluate variations in piezometric head with depth and local vertical gradients in the aquifer (Figure 13). This is especially important when aquitards hydraulically isolate permeable layers in an aquifer system. A local extraction or injection well also may influence the hydrostatic pressure profile.

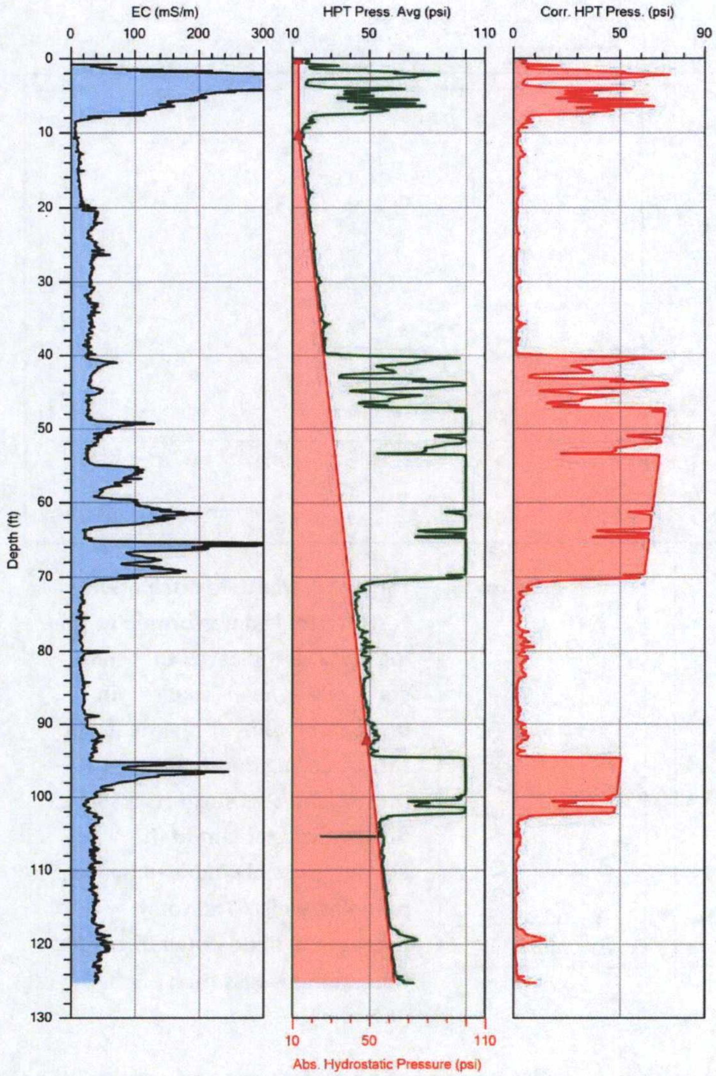


Figure 12: This log was run near Halstead, KS where brine from former oil drilling and production is starting to impact the Groundwater in the Arkansas River alluvial aquifer. The HPT average pressure along with the atmospheric and hydrostatic pressure lines are plotted on the center graph. The corrected HPT pressure (P_{inj}) is plotted on the right graph. The corrected pressure is the pressure required to inject water into the formation at the given flow rate.

The HPT pressure sensor has a maximum limit of 100 psi (690 kPa) resulting in the flat topped peaks on the HPT pressure graph (center) when the injection pressure exceeds the transducer limit.

Table 1

Calculation of Water Level from HPT Dissipation Test Data

Parameter	English		Metric	
	Value	**Units**	**Value**	**Units**
Measured Probe Depth (string pot data)	92.10	ft	28.07	m
Stabilized Formation Total Pressure (dissipation test data)	48.37	psi	333.8	kPa
*Transducer Meas. Atm. Press. (pre- & post-log reference tests)	12.97	psi	89.49	kPa
Calculated Hydrostatic Press. at depth of dissipation test	35.40	psi	244.3	kPa
Length of Water Column above HPT Port	81.76	ft	24.92	m
Static Water Level (below grade)	10.34	ft	3.15	m

*Average of pre- & post-log reference test results. One psi = 2.31 feet of water = 6.90 kPa (kiloPascal).

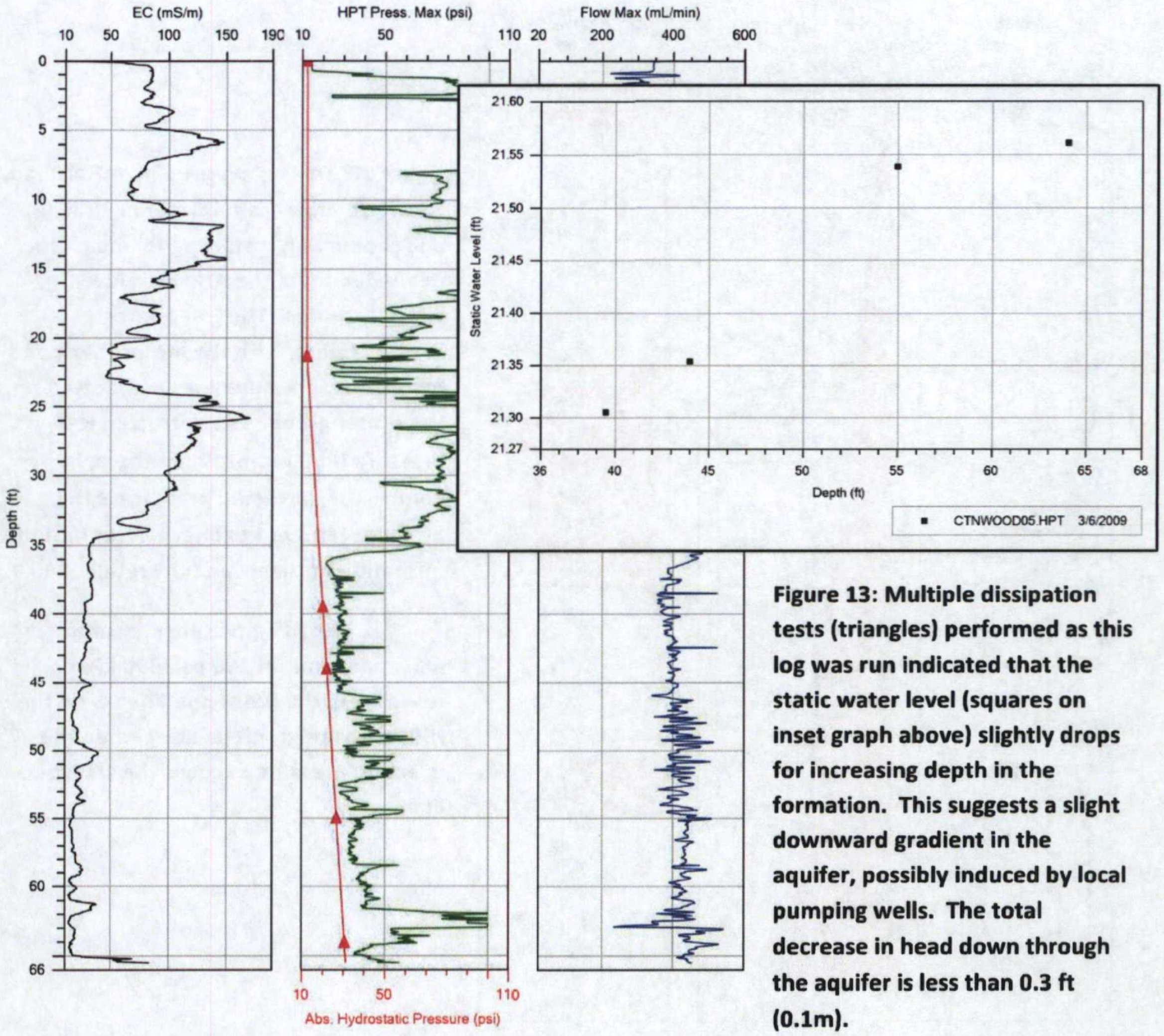


Figure 13: Multiple dissipation tests (triangles) performed as this log was run indicated that the static water level (squares on inset graph above) slightly drops for increasing depth in the formation. This suggests a slight downward gradient in the aquifer, possibly induced by local pumping wells. The total decrease in head down through the aquifer is less than 0.3 ft (0.1m).

HPT pressure dissipation tests are not used to estimate formation hydraulic conductivity (K) as done for CPTu (piezocone) dissipation tests. This is because the water in the HPT trunk-line above the local water level will interfere with the early time dissipation of the observed pressure down hole (late time stabilized pressure will be accurate). However, the dissipation test data may be used in conjunction with the pressure and flow logs to estimate K for the entire log after logging is completed (See below for further discussion on K-estimation).

Note: HPT dissipation tests in fine grained materials can take up to several hours to stabilize. If hydrostatic equilibrium pressure is not reached before the test is halted this can cause determination of erroneous hydrostatic pressures and inaccurate water level determinations if the test results are used in the DI Viewer calculations.

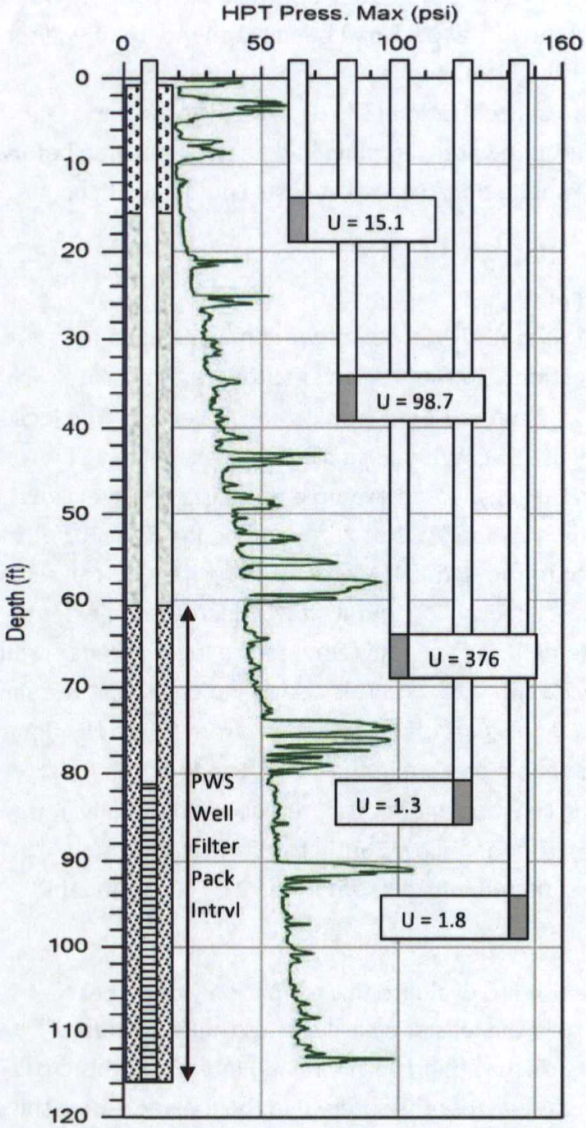


Figure 14: HPT logs were used to guide placement of DP wells at discrete intervals between clay layers (high pressure peaks) in a part of the Platte River alluvial aquifer. Uranium concentrations (µg/l) in wells higher in the aquifer exceeded the EPA MCL (30 µg/l). The extended filter pack of the 12-inch PWS well intersected the high uranium aquifer zone (After McCall et al. 2009).

Other Applications for HPT Logs

The above section discussed basic uses for HPT logs. The following section will introduce several additional applications for HPT logs that can be valuable in developing an accurate conceptual site model (CSM) and evaluating designs for site remediation. These applications range from simple use of the logs to guide placement of well screens to delineation of brine plumes and even estimation of hydraulic conductivity from HPT flow and pressure data.

Guide Placement of Well Screens

From the discussion of log interpretation above we see that zones of higher pressure indicate lower permeability materials in the aquifer which would provide poor yield to a well installed in such a zone (e.g Figure 12: 40-72ft, 95-104ft, Figure 14: 57-60ft, 74-80ft). Conversely, lower pressure zones indicate the presence of coarser grained materials with higher permeability that should yield abundant water to wells (Figure 12: 10-40ft, 73-94ft, 106-125ft, Figure 14: 60-74ft, 80-90ft and 93-112ft). During an investigation in Clarks, NE several HPT logs were run to learn about the hydrostratigraphy of the local alluvial deposits of the Platte River (Figure 14). The investigation was being conducted to determine possible sources of elevated uranium impacting the local public water supply wells at this field site (McCall et al. 2009). Direct push wells with 5 foot screens were installed in the lower pressure zones observed on the HPT logs and between the high pressure zones. This method targeted materials that would provide abundant water for sampling and information on variations of water quality with depth. During development the wells were monitored for basic water quality parameters and then later sampled for uranium and other analytes. Groundwater sample results for uranium posted on the log (Figure 14) allowed the local regulators to determine that water quality did vary significantly between the clay layers (aquitards) and two permeable zones were found to have uranium concentrations that significantly exceed the uranium MCL of 30µg/l. While the screen (80-105ft) of the nearby supply well was set below an aerially extensive aquitard (74-80ft) the gravel pack had been extended up to 60 feet below grade to enhance well yield. Unfortunately for the local town's people the gravel pack intercepted the aquifer zone with the highest uranium concentration (376 µg/l) resulting in elevated uranium in their drinking water. If the HPT logs and groundwater sampling had been performed before the costly supply wells were constructed significant remediation/treatment costs could have been avoided.

Construction & Use of Hydrostratigraphic Cross Sections

When several HPT logs are obtained across a site the DI Viewer software may be used to construct simple geologic/hydrostratigraphic cross sections. In the DI Viewer software the "Cross Section" icon is selected and then the log parameter (e.g. pressure) to be plotted is selected. The logs are added to the cross section in sequential order (Figure 15). When displayed in this fashion hydrostratigraphic features may be correlated across the logs. As an example there is a relatively low pressure (higher permeability) zone apparent from approximately 21 to 26ft deep on log BWHP01 at the left (SW) side of the cross section (Figure 15). Looking to the right (NE), across the figure, you can see that the lower pressure zone across this interval persists in each log, but it slowly decreases in extent and pressures increase across this interval toward the right. Tracing this zone to the log on the far right, one sees only 2 or 3 low pressure spikes occur in the 21-26ft interval. This clearly indicates that the sand content decreases and clay and silt content increases in this part of the formation from SW to NE along this transect. So, migration to the NW of any contaminants present in the 21-26ft zone at the log BWHP01 location would be impeded by the increasing clay content in this interval. Additionally, it is apparent that the thick, high pressure (low permeability) zone below 26ft in this formation would significantly impede the downward migration of any contaminants present in the 21-26ft permeable zone.

This same HPT pressure cross section may be used to evaluate this formation for the best location to install a local water supply well. Looking over the logs one easily notes that the interval from about 43 to 60 feet on log BWHP03 is the widest low pressure (high permeability) interval in this cross section. There are only a few spikes of increased pressure across this interval in the log, indicating this is relatively clean sand and should provide good yield to a well with minimal development.

Guide Injection of Remediation Fluids

Using the cross section we discussed above (Figure 15) we can quickly develop a qualitative assessment of where it will be easy to inject remediation fluids into the formation and where it will be more difficult. Obviously the lower pressure zones identified by the HPT log from injection of water will be sections of the formation that will generally accept injected fluids at a lower pressure (e.g. log BWHP03, 43-60ft). Conversely zones of higher HPT pressure (e.g. BWHP02, 8-18ft) will require more pressure and time to inject the same fluid and volume. The viscosity of the fluid being injected and the injection pressure will have an impact on the efficiency of the injection process. Of course if the injection pressure exceeds the local lithostatic pressure fracturing may occur. However, fracturing may occur in a random fashion and so your ability to control where injected fluids go may be poor under these conditions.

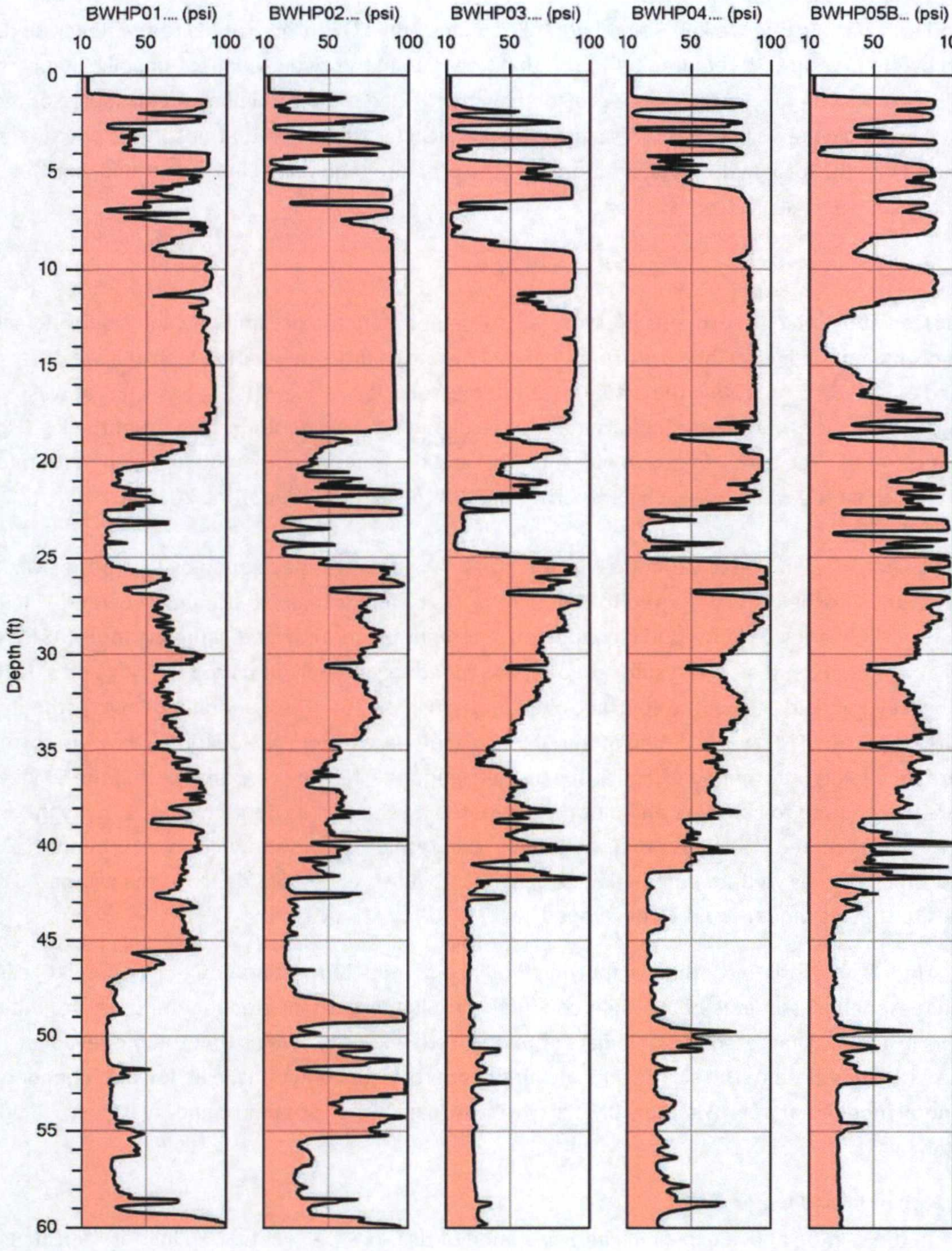


Figure 15: These five HPT pressure logs were obtained along a SW-NE transect separated by 50 ft (15 m) spacing. The DI Viewer software was used to create this cross section that provides detailed information on formation permeability and hydrostratigraphy. Lateral correlation between the logs can be used to assess migration pathways (low HPT pressure zones) and guide well placement.

Estimation of Hydraulic Conductivity

From Darcy's Law we know that hydraulic conductivity (K) is proportional to the flow rate (Q) divided by the pressure (P) required to induce that flow rate in the given sediment or soil. Simply stated this is: K Q/P. The raw HPT pressure provided by the HPT log is the total pressure observed at the depth where the water is injected. This total pressure includes the ambient atmospheric pressure at the time of the log, the local hydrostatic pressure and the pressure required to inject the fluid into the formation. So we have:

$$\mathbf{P_{total} = P_{atm} + P_{hydro} + P_{inj}}$$

As discussed above the atmospheric pressure is determined from the pre and post log response tests (Appendix II) and the hydrostatic pressure is defined by one or more dissipation tests (Figure 10) obtained as the log is run. Now the actual injection pressure [$\mathbf{P_{inj} = P_{total} - (P_{hydro} + P_{atm})}$] that was required to inject the water into the formation is calculated for each depth increment of the log (Figure 12, right column). The actual injection pressure (P_{inj}) and the measured flow rate (Q) is then used to model an estimated K value for each depth increment of the HPT log (Geoprobe 2010b).

An empirical model to estimate K for HPT Q and P_{inj} data was developed by Geoprobe (McCall & Christy 2010). One field site was used to develop the basic empirical model utilizing several HPT logs and co-located slug tests (ASTM 2006) conducted in temporary groundwater sampling tools (ASTM 2005b) at targeted depths. The resulting model was found to generally fit paired HPT log and slug test data from several field sites in the central United States (Figure 16). This general model to estimate K from the HPT Q and P data is included in the DI Viewer software (Geoprobe 2010b). Once the corrected pressure for a log is determined using log specific dissipation test(s) and response test(s) the DI Viewer software can be used to calculate and plot the estimated K value verses depth (Figure 17). As this log indicates the estimated-K value is provided at inch-scale resolution and should prove useful for risk and transport modeling as well as remediation design. To provide greater confidence in the estimated K value a site specific model could be developed.

Under appropriate conditions applying the general model for estimation of K (Figure 16) can provide reasonable estimates of hydraulic conductivity. Slug tests conducted in temporary groundwater samplers installed at targeted depths adjacent to one log (Figure 18) reveals that the model does provide estimates close to the slug test results under appropriate conditions. The lower K boundary for the general model is at approximately 0.1ft/day (0.03m/day) and the upper boundary is near 75ft/day (25m/day).

Delineation of Brine Plumes

In the section above explaining interpretation of HPT logs the fact that EC logs are sensitive to salt or brine in groundwater was discussed. Conversely, HPT pressure and flow logs are relatively insensitive to salt or brine content of the groundwater. Because of these facts we can use HPT corrected pressure (P*) and EC logs to evaluate the potential for brine, landfill leachate or seawater impact to an aquifer (Figure 19). At the field area where this log was obtained previous oil drilling and production had lead to brine releases in the shallow alluvial aquifer up gradient from where this log was

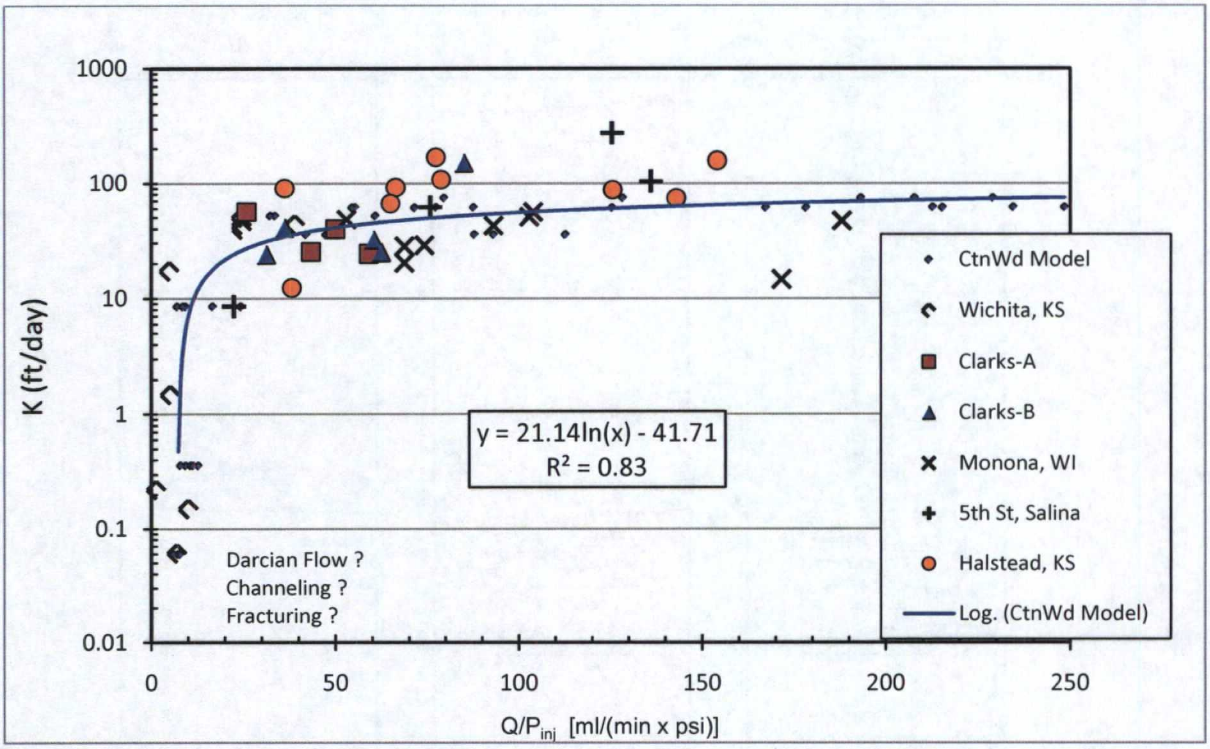


Figure 16: The general model for estimating K from HPT Q/P_{inj} was developed from logs obtained in the Smoky Hill alluvial aquifer in Salina, KS. Multiple logs were obtained at the test site and co-located slug tests were performed at selected depths with DP piezometers. Paired data for HPT Q/ P_{inj} ratios and co-located slug tests from six sites from the midcontinent U.S. also are plotted with the model curve. This demonstrates the relationship of the model to multiple site data.

obtained. A detailed review of this log (Appendix III) reveals some basic relationships between EC and P*. These are:

- When EC is relatively high and HPT pressure is low there is potential for chloride impact in the saturated aquifer
- When both EC and pressure are relatively high this generally correlates with elevated clay content and reduced permeability
- Low EC and low HPT pressure generally indicate coarse grained aquifer materials without chloride/brine impact

Targeted groundwater samples and slug tests from three zones at this location (Figure 19) confirm this general relationship. Similar results were observed at several other locations at this site and a plot of the EC/P* ratio versus chloride (Figure 20) has a strong positive correlation. This relationship will be influenced by site-specific conditions. When high chloride concentrations are present this will result in elevated EC values in the EC log (>1000mS/m), and will be readily obvious, especially when compared to low HPT pressures over the same interval (Binder 2008).

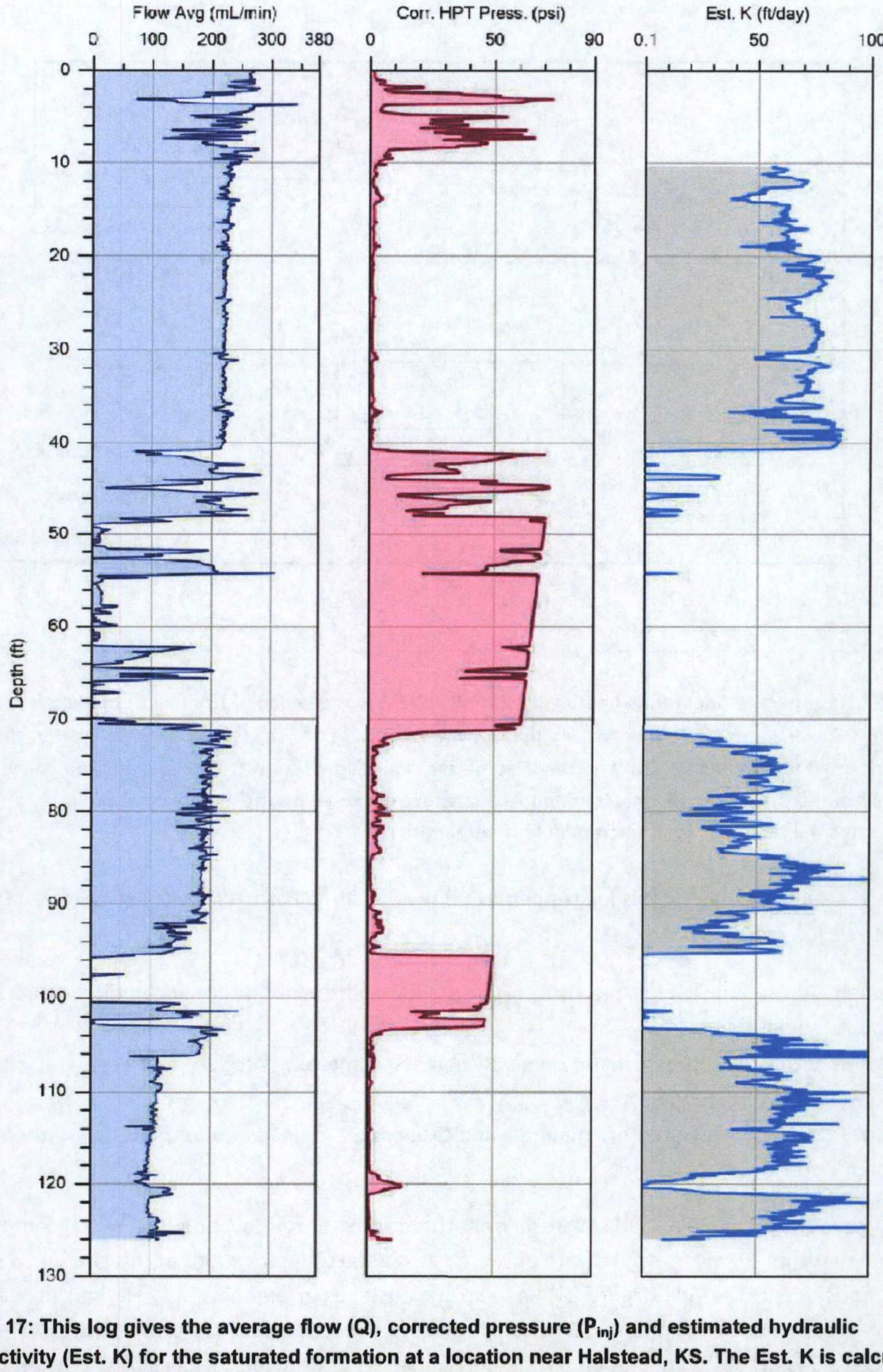


Figure 17: This log gives the average flow (Q), corrected pressure (P_{inj}) and estimated hydraulic conductivity (Est. K) for the saturated formation at a location near Halstead, KS. The Est. K is calculated based on the model in Figure 16. Note that anomalous high-K spikes occur in the estimated K where the corrected pressure approaches zero, this is an artifact of the model. The original HPT log is provided in Figure 12.

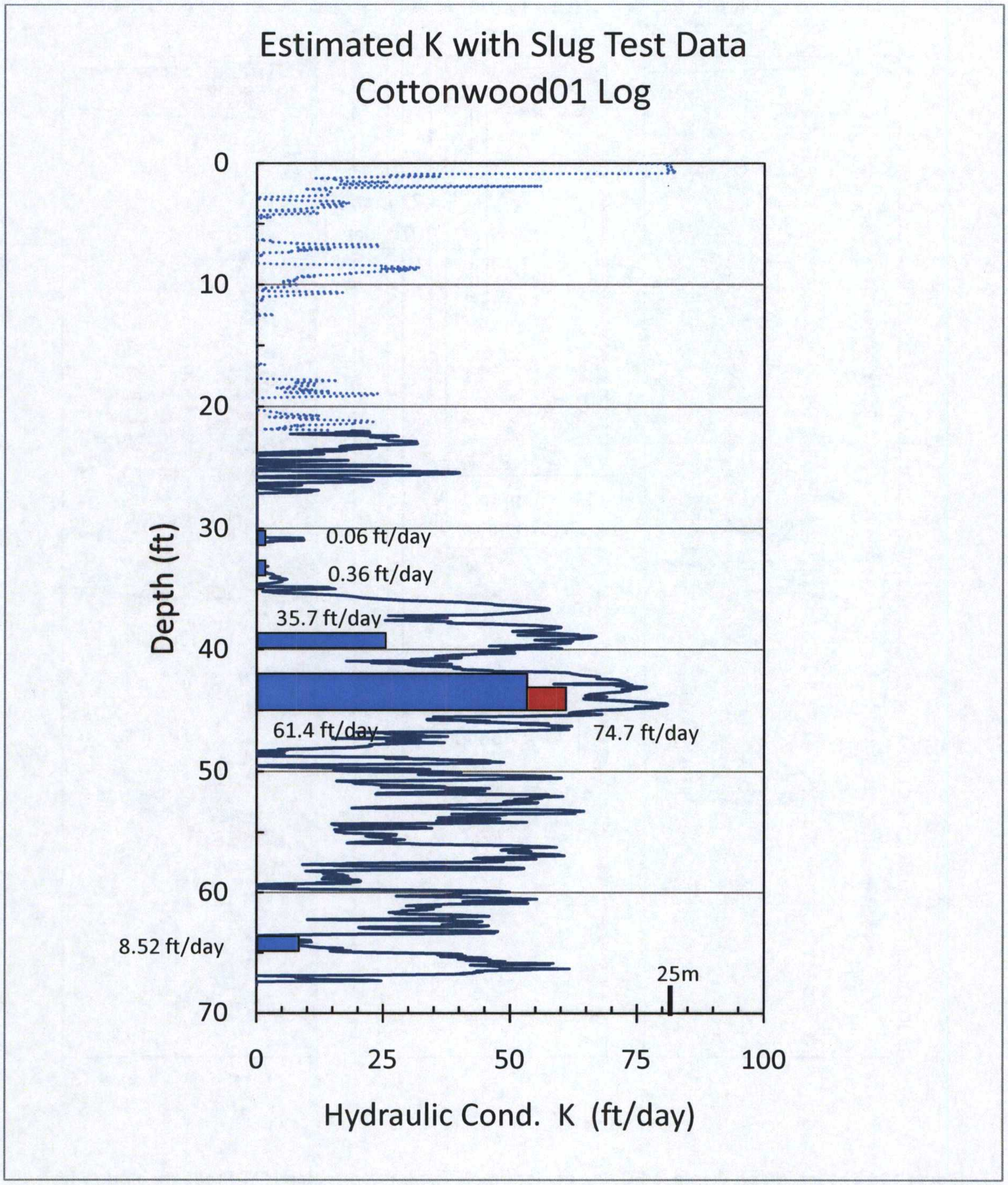


Figure 18: Log of estimated K from HPT Q/ P_{inj} along with slug test results from discrete interval slug testing at this location. Slug tests were performed in SP16 groundwater samplers with a pneumatic manifold and transducer following screen development. Note: at 45ft slug tests were conducted first over a 2ft interval (43-45ft) and then over a 3ft interval (42-45ft). Estimated K shown as dashed line above the water level (After McCall and Christy, 2010).

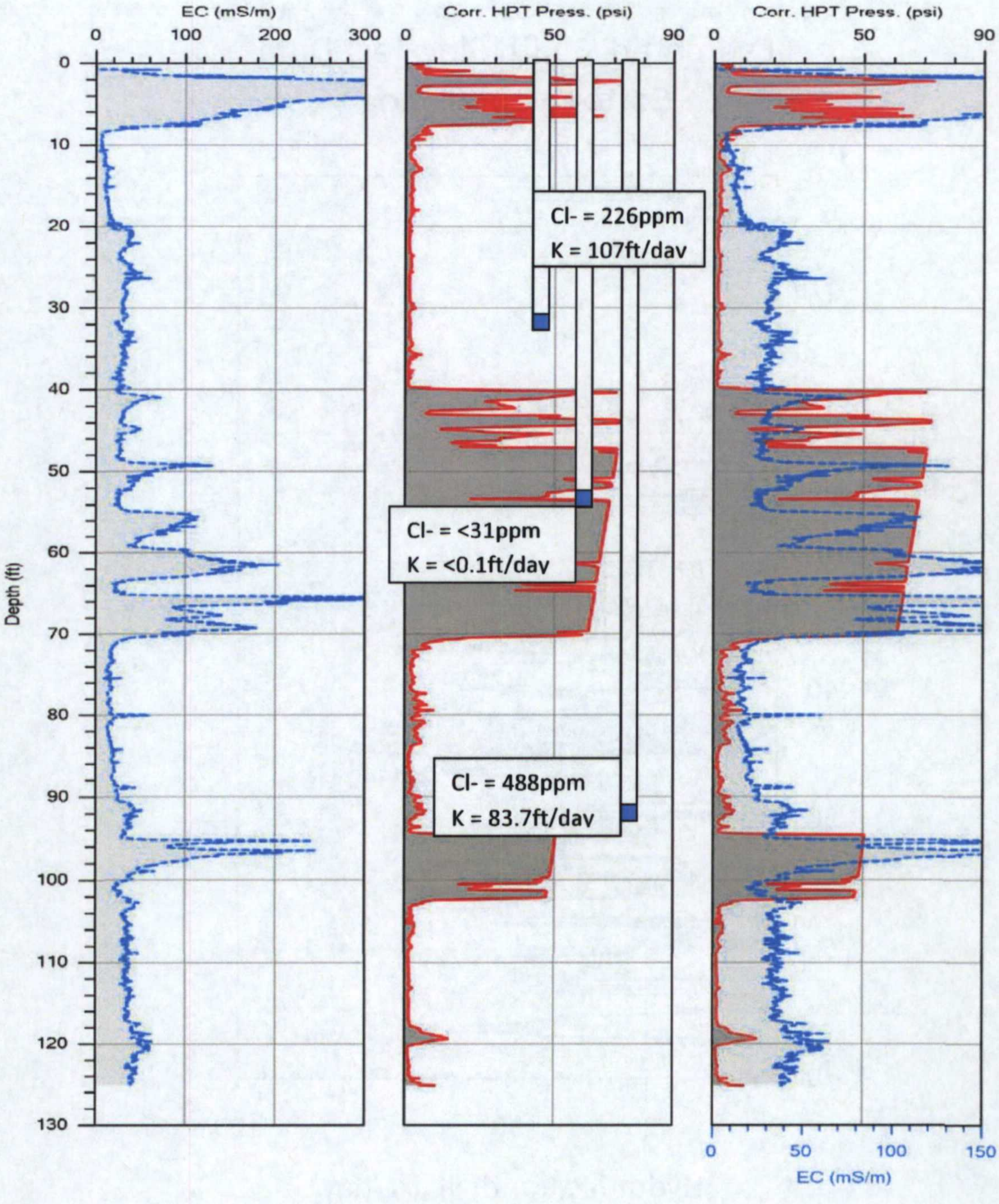


Figure 19: The left graph displays EC, the center graph displays corrected HPT Pressure along with data of Chloride concentration and hydraulic conductivity measured at the indicated depth intervals with temporary piezometers. At right is an overlay of EC and corrected HPT pressure (shaded) used to evaluate potential zones of chloride impact in this alluvial aquifer down gradient from former oil drilling and production operations. Zones where corrected HPT pressure is low (sand and gravel) but EC is elevated above a range of 10-20mS/m provides an indication of chloride impact at this site (Neshyba-Bird et al. 2009).

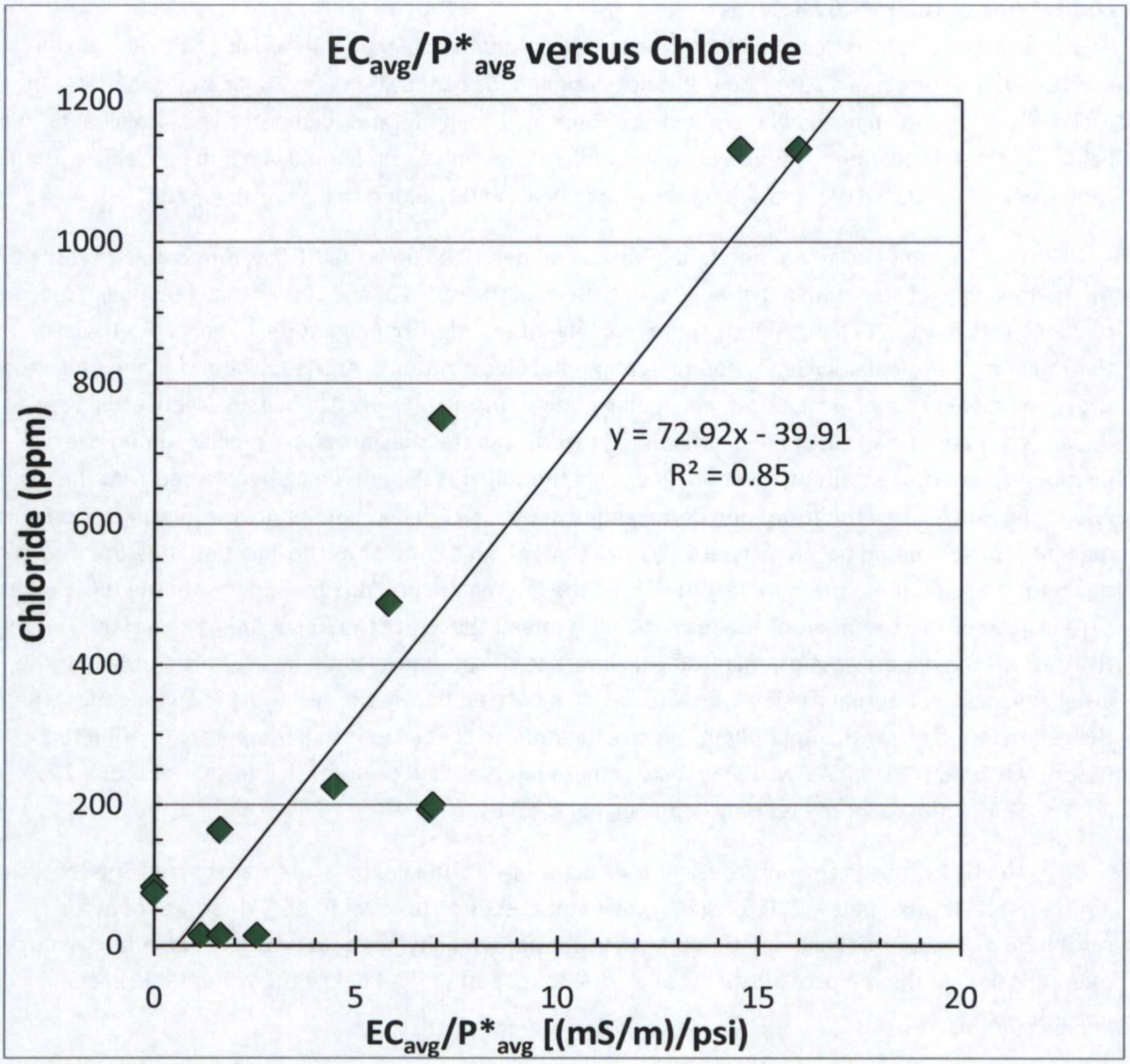


Figure 20: Data from the Halstead site was used to evaluate the relationship between chloride concentration in groundwater samples from discrete screen intervals and the ratio of the average EC to the average P_{inj} over that same depth interval. Good correlation indicates that the EC and P_{inj} data may be used to infer the presence of elevated chloride content in the groundwater at this site. Using just EC to compare to chloride will not provide a good model as EC also will be elevated where clay content of the formation is high.

Limitations of the HPT System

The HPT probe is designed for advancement into unconsolidated materials (clay, silt, sand±gravel) by direct push methods. It is not designed for penetration of consolidated sediments or rock. While the tool may be able to penetrate some light to moderately cemented soils (caliche) or lightly cemented sediments, the tough, indurated, caliche soils or similar may be impenetrable with this tool. Very dense glacial tills and sediments with cobbles and boulders will be problematic.

In its current design and method of operation described here the HPT system is able to resolve the permeability of soils with a hydraulic conductivity in the range of about 0.1ft/day (3.5E-5cm/sec) up to about 75ft/day (2.7E-2cm/sec), so approximately three orders of magnitude in range. Fortunately, this range is of particular value for geo-environmental investigations. At the lower end of the range the exact point where non-Darcian flow, channeling, fracturing, etc. (Figure 16) becomes active will vary depending on the flow rate applied, effective pressure and the specific nature (density, grain size distribution, moisture content, cementing, etc.) of the soil or sediment being penetrated. At the upper end of the range when the formation permeability becomes high enough the pressure required to inject fluid into the formation becomes relatively low. Under high K conditions the injection pressure may be equal to or less than the pressure resulting from the internal friction due to fluid flow in the HPT probe system. Under these conditions the formation K is effectively above the upper limit of what the current HPT system can discern. Simply increasing flow rate to the probe will not alleviate this problem as this also increases the internal friction/pressure due to increased flow in the system. In aquifer zones where the estimated K is near the upper limit the investigator can choose to install temporary piezometers (Geoprobe 2006c, 2010a; ASTM 2005b) across these intervals and perform slug tests (Geoprobe 2002, 2011 ; ASTM 2006) to more precisely define higher K zones.

The HPT probe is currently designed with a 100psi (~700kPa) pressure transducer. This is equivalent to approximately 230 feet (70m) of water pressure. In order to provide some room for resolution of high permeability materials from lower permeability materials this gives an effective upper operating limit in the range of 80psi (550kPa), or about 180ft (~55m) below the water table in an unconfined aquifer.

The HPT pressure and flow logs give us information on the relative permeability of the materials being penetrated. We can make inferences regarding sediment type and dominant grain size, especially when the EC log is used with the HPT pressure and flow logs. However, this is just an inference without at least some sampling of the soils and sediments being logged. A fine grained soil with abundant fractures may have permeability similar to a sandy soil. Conversely, a cemented sand and gravel sediment may have permeability similar to fine, silty clay. Log and sample wisely.

Specifications for Procuring HPT Logging Services

The experience, training and competency of the field operator for the HPT system and Geoprobe® unit will have an impact on the quality of HPT data you obtain for any project. Providing adequate specifications to your contractor or subcontractor can help assure the type and quality of data you obtain is what is required to meet your project data quality objectives. The attached outline

(Appendix IV) will provide guidance on setting up procurement specifications for HPT logging services and reporting. For further details on required equipment and tooling review the HPT operating procedure (Geoprobe 2007) and visit the Geoprobe® Direct Image website (Geoprobe-DI.com).

For quality assurance purposes it is recommended that both pre-log and post-log response tests be performed for each HPT log using the HPT Reference Tube (PN 29105). If the response test gives results outside of the control limit range (0.22psi ±10%: 1.5kPa ±10%) for the pressure sensor corrective measures should be taken. Often, simply removing, cleaning and replacing the HPT screen will correct the problem. If this is not successful the pressure sensor should be replaced before proceeding with the next log. Purge all air from the trunkline and probe prior to response testing.

In order to get full benefit of the HPT log data it is necessary to run at least one dissipation test during each log. As discussed earlier, the system operator stops probe advancement, stops flow to the probe and acquires a time data file for each dissipation test. The dissipation is allowed to run until the stable, total pressure is obtained. This will allow the investigator to calculate water levels from the HPT data as well as determine corrected pressure profiles and estimate hydraulic conductivity if desired. If the formation is stratified and sand layers are interlayered with silty-clay low permeability layers dissipation tests may be needed in each sand layer to assess changes in piezometric pressure with depth in the different sand zones. This will be valuable data to assess the existence of vertical gradients in the formation or aquifer system. Run HPT dissipation tests in sandy zones for best results and efficiency.

The procurement officer also will want to assure that adequate data and information is supplied to the project manager after the logs are obtained. All HPT data files, including information files, response test data and dissipation test data for each log should be provided to the project manager in digital format for use on Geoprobe's DI Viewer® software (free software download at www.geoprobe-di.com) . Filenames should be set up to meet proposal specifications. Field/onsite reporting may be desired to assist the project manager with making onsite decisions to achieve Triad/Accelerated site characterization goals. Include any onsite reporting requirements in the project specifications.

Summary and Discussion

The hydraulic profiling tool is a powerful system that can be used to understand the subsurface geology and hydrostratigraphy in unconsolidated soils and sediments. The HPT log can be used to evaluate the presence and location of preferential migration pathways and potential aquitards. The HPT provides the investigator with logs of injection pressure and flow rate versus depth, as well as electrical conductance of the bulk formation. These logs are independent of human interpretation, unlike a soil boring log, and so are not prone to human bias. Field quality assurance/quality control tests provide confirmation of system performance and reliability.

Interpretation of the HPT pressure log is relatively simple, with higher injection pressure indicating lower permeability and lower injection pressure indicating higher permeability. Additionally, the EC log provides a measure of independent confirmation for the HPT log. Furthermore, the HPT logging system is an effective tool to accomplish one of the primary goals of a geo-environmental investigation; that is to establish an accurate site conceptual model (CSM) of the subsurface and provide data to substantiate the model.

As reviewed above the HPT logs can be applied for many site assessment needs. These applications range from simple interpretation of local lithology/hydrostratigraphy, construction of geologic cross sections and guiding well screen placement to more complicated applications such as guiding remedial fluids injection, delineation of brine plumes/sea water intrusion and estimation of hydraulic conductivity with inch-scale resolution. The HPT system is a useful tool for the site investigator that can save time and cost to obtain an accurate CSM and help achieve remediation objectives.

References

American Society for Testing and Materials (ASTM), 1995. E1739 Standard Guide for Risk-Based Corrective Action at Petroleum Release Sites. ASTM International, 100 Barr Harbor Dr., West Conshohocken, PA. www.astm.org

ASTM, 2005. D6282-98 Standard Guide for Direct Push Soil Sampling for Environmental Site Characterization. ASTM International, 100 Barr Harbor Dr., West Conshohocken, PA. www.astm.org

ASTM, 2005b. D6001-05 Standard Guide for Direct-Push Ground Water Sampling for Environmental Site Characterization. ASTM International, 100 Barr Harbor Dr., West Conshohocken, PA. www.astm.org

ASTM, 2006. D7242 Standard Practice for Field Pneumatic Slug (Instantaneous Change in Head) Tests to Determine Hydraulic Properties of Aquifers with Direct Push Ground Water Samplers. ASTM International, 100 Barr Harbor Dr., West Conshohocken, PA. www.astm.org

ASTM, 2007. D7352 Standard Practice for Direct Push Technology for Volatile Contaminant Logging with the Membrane Interface Probe (MIP). ASTM International, 100 Barr Harbor Dr., West Conshohocken, PA. www.astm.org

Binder, Jeffrey L., 2008. Use of Hydrsulic Profiling Tool to Identify Preferential Pathways for Chloride-Impacted Groundwater Migration. Proceedings of the Sixth International Conference on Remediation of Chlorinated and Recalcitrant Compounds: Paper F-011. Battelle, Columbus, OH. www.battelle.org/chlorcon

Butler, James J., Jr., John M. Healey, G. Wesley McCall, Elizabeth J. Garnett and Steven P. Loheide, 2002. Hydraulic Tests with Direct-Push Equipment. Ground Water Vol. 40, No. 1. January-February. Pages 25-36.

Butler, James J., Jr., P. Dietrich, V. Wittig and T. Christy, 2007. Characterizing Hydraulic Conductivity with the Direct-Push Permeameter. Ground Water, Vol. 45, No. 4. Pages 409-419.

Christy, Colin D., Thomas M. Christy and Volker Wittig, 1994. A Percussion Probing Tool for the Direct Sensing of Soil Conductivity. Georpobe Systems, Salina, KS. 15 pages.

Christy, Thomas M., 1996. A Permeable Membrane Sensor for the Detection of Volatile Compounds in Soil. In Proceedings of the NGWA Outdoor Action Conference, Las Vegas, NV. NGWA Westerville, Ohio. May.

Dietrich, Peter, James J. Butler and Klaus Faib, 2008. A Rapid Method for Hydraulic Profiling in Unconsolidated Formations. Ground Water, Vol. 46, No. 2. March-April. Pages 323-328.

Dobrin, Milton B., 1976. *Introduction to Geophysical Prospecting*. McGraw-Hill, New York, NY.

Elsworth, D., and D.S. Lee, 2007. Limits in DDetermining Permeability from on-the-Fly µCPT Sounding. Geotechnique Vol. 57, No. 8. Pages 679-685.

Fetter, Charles W., 1994. *Applied Hydrogeology*, 3rd Edition. Prentice-Hall, Upper Saddle River, NJ.

Geoprobe 2002, Geoprobe® Pneumatic Slug Test Kit: Standard Operating Procedure, Tech. Bul. 19344. Revised December 2005. Replaced, January 2011. Kejr Inc., Salina, KS. www.geoprobe.com

Geoprobe, 2003. *Georpobe® Systems Tools Catalog*, V.6. Kejr Inc., Salina, KS. www.geoprobe.com

Georpobe, 2006a. Hydrostratigraphic Characterization Using the Hydraulic Profiling Tool (HPT). Tech. Bul. No. MK3099. Kejr Inc. Salina, KS. April. www.geoprobe.com

Georpobe, 2006b. Geoprobe® Macro-Core® MC5 : 1.25-inch Light-Weight Center Rod Soil Sampling System, Standard Operating Procedure. Tech. Bul. No. MK3139. Kejr Inc. Salina, KS. November. www.geoprobe.com

Georpobe, 2006c. Geoprobe® Screen Point 16 Groundwater Sampler, Standard Operating Procedure. Tech. Bul. No. MK3142. Kejr Inc., Salina, KS. www.geoprobe.com

Geoprobe, 2007. Geoprobe® Hydraulic Profiling Tool (HPT) System, Standard Operating Procedure. Tech. Bull. No. MK3137. Kejr Inc. Salina, KS. March. www.geoprobe.com

Geoprobe, 2010a. Geoprobe® SP22 Groundwater Sampler, Standard Operating Procedure. Tech. Bull. No. MK3173. Kejr Inc. Salina, KS. April. www.geoprobe.com

Geoprobe, 2010b. Tech Guide for Calculation of Estimated Hydraulic Conductivity (Est. K) Log from HPT Data. Kejr Inc. Salina, KS. November. www.geoprobe.com

Geoprobe, 2011. Geoprobe® Pneumatic Slug Test Kit (GW1600):Installation and Operation Instructions, Instructional Bul. #MK3181. Kejr Inc., Salina, KS. January. www.geoprobe.com

Griffin, Terry W., and Kenneth W. Watson, 2002. A Comparison of Field Techniques for Confirming Dense Nonaqueous Phase Liquids. Ground Water Monitoring & Remediation, Vol. 22, No.2. Spring. Pages 48-58.

Interstate Technology & Regulatory Council (ITRC), 2008. *Use of Risk Assessment in Management of Contaminated Sites*: RISK-2. ITRC 444 North Capitol Street, NW, Suite 445, Washington, DC. August. www.itrc.org

Keys, W. Scott, 1997. *A Practical Guide to Borehole Geophysics in Environmental Investigations*. CRC/Lewis Publishers, Boca Raton, FL. 176 pages.

Kram, Mark, Gary Robbins, Jessica Chau, Amvrossios Bagtzoglou, Daniel Eng, and Norm Jones, 2008. Detailed Hydraulic Assessment Using a High-Resolution Piezocone Coupled to the Geovis. NAVFAC Technical Report TR-2291-ENV, ESTCP Project CU-0421. Engineering Service Center, Port Hueneme, CA. April.

Lee, Dae Sung, Derek Elsworth and Roman Hryciw, 2008. Hydraulic Conductivity Measurement from On-the-Fly µCPT Sounding and from VisCPT. Journal of Geotech. And Geoenviron. Eng., Vol. 134, No. 12. Pages 1720-1729. December.

Liu, Gaisheng, James J. Butler Jr., Geoffrey C. Bohling, Edward Reboulet, Steve Knobbe and David W. Hydnman, 2009. A New Method for High-Resolution Characterization of Hydraulic Conductivity. American Geophysical Union: Water Res. Research, Vol. 45. W08202. 6 pages.

McCall, Wesley, James J. Butler Jr., John M. Healey, Alyssa A. Lanier, Stephen M. Sellwood and Elizabeth J. Garnett, 2002. A Dual-Tube Direct-Push Method for Vertical Profiling of Hydraulic Conductivity in Unconsolidated Formations. Environ. & Eng. Geoscience, Vol. VIII, No. 2. May. Pages 75-84.

McCall, Wesley and Thomas M. Christy, 2010. Development of a Hydraulic Conductivity Estimate for the Hydraulic Profiling Toll (HPT). The 2010 North American Environmental Field Conference & Exposition: Conference Program with Abstracts: Session VII. January. www.envirofieldschool.com

Neshyba-Bird, Dolores, Marcia K. Schulmeister, G. Wesley McCall, and Thomas M. Christy. Direct-Push Electrical Conductivity Assessment of an Historic Brine Plume in the Equus Beds Aquifer, KS. Geological Society of America. http://gsa.confex.com/gsa/2010NC/finalprogram/abstract_171297.htm

Robertson, P.K., J.P. Sully, D.J. Woeller, T. Lunne, J.J.M. Powell and D.G. Gillespie, 1992. Estimating Coefficient of Consolidation from Piezoncone Tests. Can. Geotech. J. Vol. 29. Pages 539-550.

Schulmeister, M.K., J.J. Butler, Jr., J.M. Healey, L. Zheng, D.A. Wysocki and G.W. McCall, 2003. Direct-Push Electrical Conductivity Logging for High-Resolution Hydrostratigraphic Characterization. Ground Water Mon. & Rem. Vol. 23, No. 3. Summer. Pages 52-62.

U.S. Environmental Protection Agency (EPA), 1998. *Seminars: Monitored Natural Attenuation for Ground Water*. Office of Research and Development, Washington, D.C. EPA/625/K-98/001. September.

U.S. EPA, 2000. Innovations in Site Characterization: Geophysical Investigation at Hazardous Waste Sites. OSWER (5102G), Washington, D.C. EPA 542-R-00-003. August. www.epa.gov/tio

U.S. Geological Survey (USGS), 1992. Water Supply Paper 2254: Study and Interpretation of the Chemical Characteristics of Natural Water, 3rd Edition. U.S. Dept. of the Interior. U.S. Government Printing Office, Washington, D.C. 263 pages with attachments.

Wilson, John T., Randall R. Ross and Steven Acree, 2005. Using Direct-Push Tools to Map Hydrostratigraphy and Predict MTBE Plume Diving. Ground Water Mon. & Rem. Vol. 25, No. 3. Summer. Pages 93-102.

List of Appendices

I. HPT System Tool Configuration and System Components

II. The HPT Information File

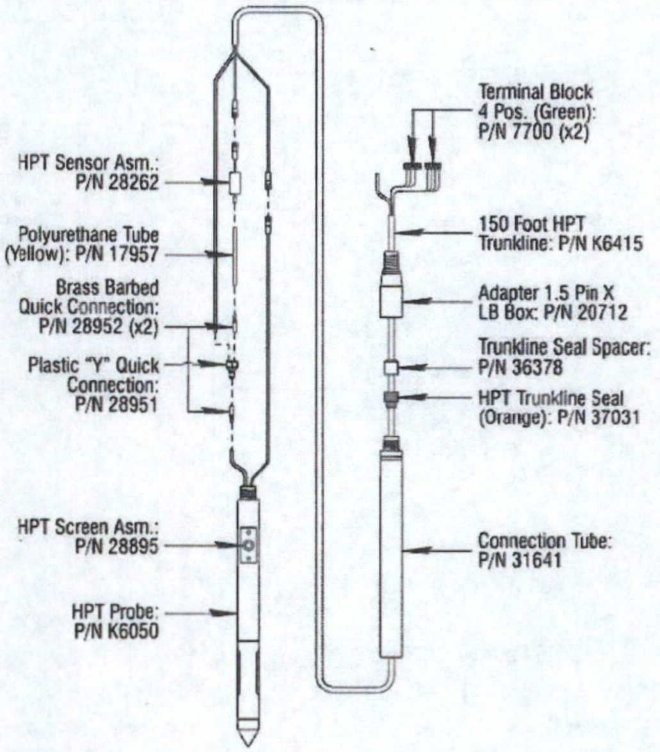
III. Detailed Log Review Regarding the Assessment of Brine or Seawater Impact

IV. Outline of Specifications for Procuring HPT Logging Services

Appendix I

HPT Tool Configurations and System Components

HPT Probe, Connection Tube and Trunkline Assembly for 1.5-inch Rod System



Parts

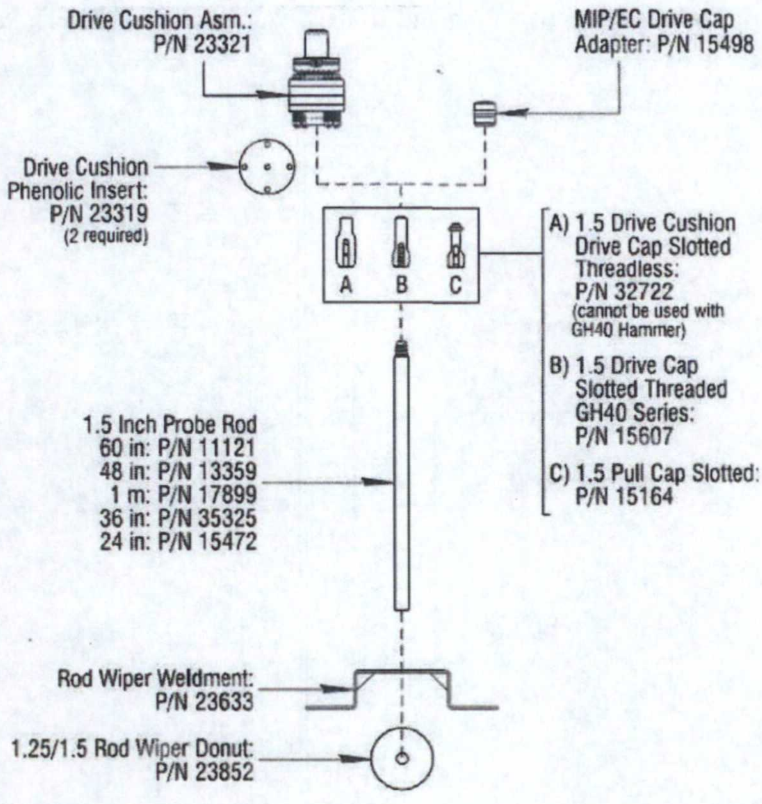
P/N	Description
7700	Terminal Block 4 Pos. (Green) (2 required)
K6415	150 Foot HPT Trunkline
20712	Adapter 1.5 Pin X LB Box
36378	Trunkline Seal Spacer
37031	HPT Trunkline Seal (Orange)
31641	Connection Tube
28262	HPT Sensor Asm.
17957	Polyurethane Tube (Yellow)
28952	Brass Barbed Quick Connection (2 required)
28951	Plastic "Y" Quick Connection
28895	HPT Screen Asm.
K6050	HPT Probe

Visit www.geoprobe-di.com for latest HPT accessories and information on larger tooling systems.

HPT Tool Configurations and System Components

(continued)

1.5-inch Drive Rods and Accessories for HPT Logging



Parts

P/N	**Description**
23321	Drive Cushion Asm.
23319	Drive Cushion Phenolic Insert (replacement part, two required)
15498	MIP/EC Drive Cap Adapter
32722	1.5 Drive Cushion Cap Slotted Threadless (cannot be used with GH40 Hammer)
15607	1.5 Drive Cap Slotted Threaded GH40 Series
15164	1.5 Pull Cap Slotted
	1.5 Inch Probe Rod:
11121	60 in
13359	48 in
17899	1 m
35325	36 in
15472	24 in
23633	Rod Wiper Weldment
23852	1.25/1.5 Rod Wiper Donut

Visit www.geoprobe-di.com for latest HPT accessories and information on larger tooling systems.

Appendix II

The HPT Information File

```
Pre-Log EC Load Tests

 Test    Target (mS/m)    Actual (mS/m)    % Diff  P/F
Test 1       195.0            197.4          1.2  PASS
Test 2        97.0             98.2          1.3  PASS
Test 3        24.0             24.6          2.5  PASS


HPT 2-27-10 1.zip

SITE INFORMATION -- DIRECT IMAGE HPT PROBE

Geoprobe DI Acquisition Software for Windows
Version: 1.1   Build: 10120

COMPANY: Geoprobe
OPERATOR: KARBAJ
PROJECT ID: Intern
UNITS: ENGLISH
PROBE AND ARRAY: HPT Probe with Wenner Array
60 INCH STRING POT USED
ROD LENGTH: 4 feet
HPT IDEAL COEFFS:        2.2696e1,-2.2356
HPT SENSOR CAL NUMBERS: (ideal)



PRE-LOG RESPONSE VALUES

PRE TEST TIME: Thu May 27 2010 13:36:37

        TEST              HPT PRESSURE (psi)      FLOW (mL/min)    HPT PRESSURE (kPa)

TOP with FLOW=0            16.513                   0.0             113.856
TOP with FLOW>0            17.264                 289.1             119.029
BOTTOM with FLOW=0         16.308                   0.0             112.441
BOTTOM with FLOW>0         17.031                 318.6             117.428

EXPECTED FLOW=0 HPT DIFF.: 0.22 psi (1.5 kPa) +/- 10%
  ACTUAL FLOW=0 HPT DIFF.: 0.21 psi (1.4 kPa)

TRANSDUCER TEST PASSED



LOG START TIME: Thu May 27 2010 13:53:21

LOG END DEPTH: 64.65 ft
LATITUDE: 0.000000000
LONGITUDE: 0.000000000
ELEVATION: 0.00 METERS  0.00 FEET
LOG END TIME: Thu May 27 2010 15:32:30
```

The HPT Information File

(Continued)

```
POST-LOG RESPONSE VALUES

POST TEST TIME: Thu May 27 2010 15:33:54

        TEST              HPT PRESSURE (psi)      FLOW (mL/min)   HPT PRESSURE (kPa)


TOP with FLOW=0            16.472                     0.0           113.570
TOP with FLOW>0            17.030                   285.5           117.415
BOTTOM with FLOW=0         16.267                     0.0           112.159
BOTTOM with FLOW>0         16.847                   289.0           116.159

EXPECTED FLOW=0 HPT DIFF.: 0.22 psi (1.5 kPa) +/- 10%
  ACTUAL FLOW=0 HPT DIFF.: 0.20 psi (1.4 kPa)

TRANSDUCER TEST PASSED


Post-Log EC Load Tests

 Test    Target (mS/m)   Actual (mS/m)   % Diff  P/F
Test 1       195.0          197.9          1.5  PASS
Test 2        97.0           98.8          1.9  PASS
Test 3        24.0           25.1          4.8  PASS
```

Appendix III

Detailed Log Review Regarding the Assessment of Brine or Seawater Impact

(Notes for the HPT Log in Figures 8 and 15)

Some details to note about this log:

- 8-10 ft: low EC, correlates with dry sand above water level (see fig. 8 also)
- 10-20ft: EC slowly rises while pressure slowly drops.
  Suggests increasing EC not due to fines .
- 20-40ft: EC goes up and stays around 40mS/m while pressure stays low.
  Suggests elevated chloride content in this zone.
  Groundwater sample at 30-32 ft = 226ppm chloride.
- 40-70ft: Spikes/peaks in EC correlate with increased pressure over this zone.
  Indicates elevated EC and pressure due to lower permeability and increased clay content across this interval
  Groundwater sample at 52-54 ft = <31ppm chloride.
- 70-94ft: Slowly rising EC and some variability in low pressure across this interval.
  Intervals of slightly higher pressure suggest some clay may be present in those intervals.
  Slowly increasing EC indicates chloride content may slowly increase.
  Groundwater sample at 90-92ft = 488ppm chloride.
- 94-104: Higher EC and increased pressure.
  Indicates lower permeability and increased clay content.
- 104-125: EC at about 40mS/m and low pressure except at about 120ft.
  Again indicates some chloride in sandy saturated formation.
  Increase EC and P around 120ft indicates increased clay (clay lens).
  No water samples collected in this zone.

To summarize, the basic relationships between EC and P* are:

- When EC is relatively high and HPT pressure is low there is potential for chloride impact in the saturated aquifer
- When both EC and pressure are relatively high this generally correlates with elevated clay content and reduced permeability
- Low EC and low HPT pressure generally indicate coarse grained aquifer materials without chloride/brine impact

Targeted groundwater samples and slug tests from three zones at this location (Figure 15) confirm this general relationship.

Appendix IV

Specifications for Procuring HPT Logging Services

The experience, training and competency of the field operator for the HPT system and Geoprobe® unit will have a significant impact on the quality of HPT data you obtain for any project. Providing adequate specifications to your contractor or subcontractor can help assure the type and quality of data you obtain is what is required for your project data quality objectives . The following outline will provide guidance on setting up procurement specifications for HPT logging services and reporting. For further details on required equipment and tooling review the HPT operating procedure (Geoprobe Technical Bulletin # MK3137).

HPT System Specifications

- Data Acquisition rate — 5Hz
- Recommended Probe Advancement Rate — 2cm/sec
- Electrical Conductivity Array — Wenner Array, 4-pole electrode
    - Optional dipole electrode array
- Working Depth Maximum (100 psi) — 180ft (55m) below water table
- Depth Tracking : String Pot (depending on probe unit model) — SC160 or SC160-100
- Flow controller/pump (PN K6000) — 0-1000 ml/min: 500psig max

HPT Probe & Trunkline Specifications

- HPT Probe : 1.5-inch rod system — PN K6050
- HPT Probe : 2.25-inch rod system — PN K8050
- HPT Screen, stainless steel, replaceable — PN 28895
- Pressure Sensor, 0-100 psia (0-690kPa) — PN 28262
  (± 2.5% full scale: max over pressure 400psia/2500kPa)
- Trunkline, 150ft length/120ft depth — PN K6415

Computer Software & Hardware Specifications

(Either the Geoprobe field computer FC5000 or the field instrument FI6000 and a portable computer will be required.)

- FI6000 Field Instrument — PN FI6000 and
- Portable Computer with Windows XP Service Pack 3, Vista, or Windows 7 OS
    - Minimum PC requirements: 1.5 GHZ processor, 1GB RAM, 500MB free hard drive space, CD/DVD drive, USB 2.0 socket, minimum screen resolution of 1024 x 768.

Or

- FC5000 Field Computer PN FC5000

- DI Acquisition Software PN K6020
- DI Viewer Software Version 1.3 (or most recent release)

HPT System Power Requirements

- The HPT system, including all electronics, computer, and pump, may be operated from a single 15amp, 120V circuit. This is easily supplied by a portable generator.

Geoprobe Unit specifications

- To advance 1.5-inch rod system HPT 5400, 6600 and 7000 Series Machines (e.g. 54DT, 6620DT, 6625CPT, 7720DT, 7822DT etc.)
- To advance 2.25-inch rod system HPT 7000 & 8000 Series Machines (e.g. 8040DT, 8140DT, 7822DT, 7730DT, etc.)

Data & Reporting Specifications (in field/final)

- In Field: print of log and/or digital copy with ID and location information
- Final reporting:
    - Digital files complete with all field QA test results.
    - Summary table of log filenames, total depths, locations and description of any deviations from protocol or work plan.

Field Quality Assurance/Quality Control Specifications

HPT Reference Tube PN 29105
EC Test Load PN 37785
EC Test Jig PN SC463
Pre-log pressure transducer response test and EC Array test load results.
Post log pressure transducer response test and EC Array test load results.
Dissipation tests (minimum 1 per log)

Tool String Specifications for 1.5-inch Rod System

(See Appendix I or www.geoprobe-di.com)

Tool String Specifications for 2.25" Rod System

(See Appendix I or www.geoprobe-di.com)

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